LETTUCE TRANSPLANT ROOT AND SHOOT GROWTH AND DEVELOPMENT IN RELATION TO NITROGEN, PHOSPHORUS, POTASSIUM, AND WATER MANAGEMENT

By

PUFFY SOUNDY

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In loving memory of my eldest brother, Paul Walter Soundy, who departed from us March 31, 1995. Walter has been, and will continue to be my role model.

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TABLE OF CONTENTS

Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

LETTUCE TRANSPLANT ROOT AND SHOOT GROWTH AND DEVELOPMENT IN RELATION TO NITROGEN, PHOSPHORUS, POTASSIUM, AND WATER MANAGEMENT

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Chairperson: Daniel J. Cantliffe
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Lettuce (*Lactuca sativa* L.) transplants grown with floatation irrigation often show limited root growth, resulting in root systems not pulling out completely from the transplant flat, and poor establishment in the field. 'South Bay' lettuce transplants grown in a peat+vermiculite media in the greenhouse were fertilized with varying concentrations of N, P, and K, via floatation irrigation at selected frequencies, to determine optimum nutrient and water management for production of high quality transplants, with sufficient roots to fill a 11 cm^3 tray cell, and for rapid field establishment.

Phosphorus at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ applied every two to four days, increased fresh and dry shoot and root

mass, root length and area, leaf area, pulling success, leaf tissue P, relative growth rate (RGR), specific leaf area (SLA), leaf area ratio (LAR), leaf mass ratio (LMR), but reduced root:shoot ratio (RSR), net assimilation rate (NAR), and root mass ratio (RMR). Quality transplants and the earliest and greatest head mass were obtained by fertigating every two days with 15 $mg \cdot L^{-1}$ P.

Floatation fertigation with K at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ applied every two to four days, increased fresh and dry root mass only when the concentration of water extractable K in the media was less than 15 $mg \cdot kg^{-1}$, but when higher (24 $mg \cdot kg^{-1}$), root mass was unaffected. Fresh and dry shoot mass, leaf area, RSR, RGR, LMR, and RMR were unaffected by applied K, regardless of the initial K concentration in the media. Lettuce growth and yield in the field was not affected by pretransplant K.

To determine the optimum N concentration and fertigation frequency, transplants were fertigated every day or every second, third, or fourth day with N at 0, 30, 60, 90, or 120 $mg \cdot L^{-1}$. Nitrogen at 30 $mg \cdot L^{-1}$ (summer) or 60 $mg \cdot L^{-1}$ (fall, winter, or spring) maximized root growth, provided that fertigation frequency was daily or every second day. Therefore, N concentration and fertigation frequency must be considered together. Pretransplant N improved lettuce head mass and reduced time to maturity.

CHAPTER 1

INTRODUCTION

Unsatisfactory results in stand establishment of direct-seeded lettuce crops using both pelleted and raw seed, particularly during conditions of environmental stress, has led to the use of transplants as a means of establishing economically viable plant stands (Cliffe, 1989). Guzman et al. (1989) found that superior plant stand was the major factor resulting in increased marketable yields from transplanted crisphead and romaine lettuce. They concluded that perhaps growers in south Florida, with harsh and unreliable weather, could minimize economic losses and become more reliable suppliers of lettuce if a portion of the lettuce crop was transplanted. According to Klassen (1986), other reasons growers were transplanting rather than direct-seeding included better plant-to-plant uniformity especially for a once-over harvested crop such as lettuce, early season weed control, more precise spacing of plants, and elimination of the need to thin densely seeded rows.

The environmental conditions to which vegetable transplants are exposed to during their early growth play an

important role in final crop yield (Masson et al., 1991b). The early growing environment of transplants can be manipulated in ways that are not possible with direct-seeded crops (Wurr & Fellows, 1982). Several factors that are known to affect vegetable transplant size, quality, and growth in the field are root container size (Nicklow and Minges, 1962; Knavel, 1965; Dufault and Waters, 1985; Weston and Zandstra, 1986; Weston, 1988; Hall, 1989; Kemble et al., 1994; Liptay and Edwards, 1994; Maynard et al., 1996; Nicola and Cantliffe, 1996), seedling nutrition before transplanting (Jaworski and Webb, 1966; Jaworski et al., 1967; Kratky and Mishima, 1981; Dufault and Waters, 1985; Tremblay and Senécal, 1988; Weston and Zandstra, 1989; Garton and Widders, 1990; Masson et al., 1991a, b; Melton and Dufault, 1991; Dufault and Schultheis, 1994), transplant age (Chipman, 1961; Leskovar et al., 1991), and transplant storage (Dufault and Melton, 1990; Leskovar and Cantliffe, 1991). Irrigation systems could also influence transplant growth and development both in the greenhouse and subsequently during the field production cycle (Leskovar and Cantliffe, 1993; Leskovar and Heineman, 1994).

Containerized vegetable transplants grown in greenhouses can either be overhead irrigated or subirrigated. A floatation or subirrigation system was constructed by Speedling, Inc. as an alternative method to

the conventional overhead irrigation (Thomas, 1993). While disease control is the major benefit of the floatation system because leaves are maintained dry, according to Anon. (1986) there are other advantages. There are no variations in plant growth due to uneven watering and fertilization from an overhead irrigation system. The end result is more uniform plant growth. Furthermore, because there is no overhead irrigation, pesticides remain on the plant longer, making re-application less frequent and reducing both pesticide material and labor costs. According to Anon., part of the success of the system is the direct result of the transplant flat. The expanded polystyrene flat floats, making the approach to this type of bottom irrigation possible.

Using the floatation system, Leskovar and Cantliffe (1993) improved uniformity and quality of pepper transplants, compared to using overhead irrigation. When drought stress and root pruning methods were used to harden and prevent stem elongation in fresh-market tomato transplants grown with a floatation system, an increase in lateral root elongation and a decrease in shoot:root ratio were reported (Leskovar et al., 1994). A reduction in shoot:root ratio and an improvement in water-use efficiency of pepper transplants were also reported by Leskovar and

Heineman (1994), when plants were produced via the floatation system of irrigation.

However, growers have not been able to produce the highest quality lettuce transplants on a seasonal basis using the floatation system. A well developed root system is essential so that transplants can be easily pulled from the transplant flat, or pushed out utilizing a mechanical transplanter. If shoots are too long, the plants will tend to fall over, resulting in easily damaged plants and scorched leaves especially when transplanted onto plastic-mulched beds. If shoots are too short, they cannot be easily handled and can be trapped under plastic mulch. When using the floatation system of irrigation, careful management of fertilization is important since large amounts of fertilizers, especially N, can greatly increase lettuce transplant shoot growth at the expense of root growth (Tremblay et al., 1987; Tremblay and Senécal, 1988; Masson et al., 1991a).

The overall objective of this research was to optimize fertilizer and irrigation programs to produce an ideal lettuce transplant, with optimum shoot and root development for rapid field establishment and high quality yields, under the floatation system of irrigation.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Approximately 4,000 ha of crisphead lettuce were grown in Florida during the 1993-94 production season, mostly on the Histosols around Lake Okeechobee and Zellwood (Anon., 1995). However, decline of the Histosols due to oxidation and competition with other lettuce production areas such as California have limited lettuce production on the organic soils. Cantliffe (1990) suggested that the expansion of lettuce production into the abundant sandy soils of Florida could greatly increase lettuce production potential in Florida. Commercially acceptable yields of high quality from sandy soils require new production systems such as plastic mulch and transplants instead of the traditional direct-seeding used on Histosols. Florida growers have, however, been unable to produce lettuce transplants with suitable root development especially under a desirable floatation or subirrigation system, for transplanting into sandy soils. Knowledge of the factors which influence transplant growth

such as plant nutrition, irrigation, supplementary lighting, and temperature, is therefore important to produce quality transplants.

Lettuce Transplant Nutrition and Water Requirements

Vegetable transplants grown in plug cells require careful management of fertilizers (Dufault and Waters, 1985; Weston, 1988) due to limited volume in the cell and high seedling densities. Concentrations of essential plant nutrient elements within media are frequently insufficient to sustain plant growth for an extended period (Garton and Widders, 1990). Production of quality transplants is a prerequisite to a successful crop, especially in lettuce where the period of containerized transplant growth comprises up to 30 % of the total crop production time (Karchi et al., 1992).

Kratky and Mishima (1981) grew lettuce transplants by misting them with either 0, 200, 600, or 1800 $mg \cdot L^{-1}$ of a water soluble 13N-11P-21K fertilizer. Misting was performed twice daily with an application rate of 3.8 $mm \cdot day^{-1}$. Plants were transplanted to the field and grown to maturity. A foliar application of 200 to 600 $mg \cdot L^{-1}$ 13N-11P-21K plus 4 to 8 g of 8N-14P-7K preplant fertilizer per liter of media for the 200 $mg \cdot L^{-1}$ foliar fertilizer and 0 to 4 $g \cdot L^{-1}$ for the

600 mg·L^{-1} rate was recommended. No foliar fertilization was found undesirable since transplant mass, head firmness, and head mass were reduced. The 1800 mg·L^{-1} foliar rate with added preplant fertilizer was also undesirable since it caused production of excessively tender transplants, fewer saleable heads, and smaller head size. Differences at the time of transplanting were larger than 15-fold among treatments. However, at crop harvest, differences were less than 30 % for average head mass.

Tremblay and Senécal (1988) grew lettuce, broccoli, pepper, and celery transplants in a growth chamber maintained at 95 % RH and a day/night temperature of 23/18 °C. Plants were watered every morning with distilled water. Fertilization treatments were initiated at emergence and were done to runoff every afternoon. Treatments were factorial combinations of 150 or 350 mg·L^{-1} N and 50, 200, or 350 mg·L^{-1} K. Growth measurements were made at 18, 20, 31, and 38 days after sowing for lettuce, broccoli, pepper, and celery, respectively. Nitrogen at 350 mg·L^{-1}, compared to 150 mg·L^{-1} N, increased leaf area and shoot dry mass of celery, broccoli, pepper, and lettuce, but reduced the percentage of shoot dry matter for all plant species except celery, which was not affected. Broccoli and pepper specific leaf area (SLA) was enhanced by increased N concentration while celery SLA was reduced and lettuce was unaffected.

Root dry mass was reduced with 350 $mg \cdot L^{-1}$ N, compared to 150 $mg \cdot L^{-1}$ N, for all species except for pepper, which was not affected. The root:shoot ratio of all species was reduced by 350 compared to 150 $mg \cdot L^{-1}$ N. Tremblay and Senécal (1988) concluded that 150 $mg \cdot L^{-1}$ N, compared to 350 $mg \cdot L^{-1}$ N, led to production of high quality transplants.

For K, Tremblay and Senécal found that celery leaf area increased linearly with K concentration but the increase for broccoli was curvilinear. Leaf area of lettuce increased with K at 350 $mg \cdot L^{-1}$ N, but there was no response detectable with 150 $mg \cdot L^{-1}$ N. They also reported that there were indications that the expansion of lettuce leaves was driven primarily by shoot dry-mass accumulation. They supported this statement by two observations: 1) increases in leaf area followed increases in shoot dry matter accumulation; and 2) SLA was not significantly modified by N and K treatments, indicating that leaf expansion was matched by a concomittant increase in shoot dry matter. Root growth characteristics and root:shoot ratio for broccoli, celery, and lettuce were not affected by K fertilization. The percentage of pepper root dry matter, however, decreased linearly with increasing K concentration.

Masson et al. (1991a) increased shoot dry mass for all plant species tested by high concentrations of N fertilization. Nutrient solutions with N at 400 $mg \cdot L^{-1}$

increased celery, lettuce, broccoli, and tomato shoot dry mass by 37 %, 38 %, 61 %, and 38 %, respectively, compared with 100 $mg \cdot L^{-1}$ N. Overhead fertigation was performed twice daily to partial runoff. Increasing the N concentration from 100 to 400 $mg \cdot L^{-1}$ decreased the percentage of shoot dry matter in all species. A similar response was previously reported for celery, lettuce, broccoli, and pepper (Tremblay at al., 1987; Tremblay and Senecal, 1988). Leaf area ratio (LAR) of broccoli and tomato increased in a curvilinear fashion with N concentration. The LAR and specific leaf area (SLA) of broccoli and tomato changed in a similar way in response to lighting and fertilization treatments.

Increasing N fertilization decreased celery, lettuce, and broccoli root dry mass (Masson et al., 1991a). Tomato dry root mass increased in a linear fashion to N fertilization as noted by Weston and Zandstra (1989). Tomato root dry mass was 16 % higher with 400 than with 100 $mg \cdot L^{-1}$ N. Root:shoot dry mass ratio decreased in a curvilinear fashion in relation to N concentration in celery, lettuce, and broccoli but in a linear fashion for tomato. For celery and lettuce, this decrease was more evident under increased light intensity.

Masson et al. (1991b) reported that increasing the supply of N to the transplant, resulted in a linear increase in total and marketable yield of celery, with the highest

yields obtained with 300 $mg \cdot L^{-1}$ N. Compared with N at 100 $mg \cdot L^{-1}$, total and marketable yields obtained from celery transplants fertilized with 300 $mg \cdot L^{-1}$ were increased by 16 % and 15 %, respectively. There was an increase of 16 % in the marketable head mass of lettuce when transplants were fertilized with 400 $mg \cdot L^{-1}$ N, compared with 100 $mg \cdot L^{-1}$ N. The use of high concentrations of N in transplant production not only increased head mass at harvest, but also promoted earlier maturity. Marketable mass and diameter of inflorescence of broccoli increased linearly with increasing concentrations of N fertilization. Increases of marketable mass of broccoli were measured for transplants fertilized with 400 $mg \cdot L^{-1}$ N, rather than those fertilized with 100 $mg \cdot L^{-1}$. In general, Masson et al. found that tomato yields were negligibly affected by lighting and N treatments.

Guzman (1993) compared two tray cell sizes and three formulas of soluble fertilizers on quality of crisphead lettuce transplants. The transplants received four nutrient applications in four weeks. Flats were floated in nutrient solution containing 60 $g \cdot L^{-1}$ fertilizer. Irrigation was by means of daily overhead misting, except for days when fertilizers were applied. During transplant production, more growth occurred with high N (20N-8.6P-16.7K) and least with high P (9N-19.4P-12.5K), regardless of the season. Guzman also reported that lettuce transplants grown under high N

were larger than desired and bruised more during transplanting, resulting in slower recovery from transplant shock. Lettuce transplants produced with high P were the smallest, and according to Guzman, this probably indicated an improper ratio of N and P. Transplants produced with medium P (15N-14.2P-15K) had the best quality. In the field, however, yields were not significantly different due to pretransplant fertilizer treatments.

Karchi et al. (1992) also investigated the response of lettuce transplants to varying concentrations of N and P. Nutrient solutions were prepared from liquid phosphoric acid and granular ammonium nitrate (33 % N) to give nutrient solutions portioned to 175 $mg \cdot L^{-1}$ N:75 $mg \cdot L^{-1}$ P; 292 $mg \cdot L^{-1}$ N:25 $mg \cdot L^{-1}$ P; 58 $mg \cdot L^{-1}$ N:126 $mg \cdot L^{-1}$ P and 32 $mg \cdot L^{-1}$ N:137 $mg \cdot L^{-1}$ P. They also compared these nutrient solutions to a water only treatment and to a water treatment supplemented by 175 $mg \cdot L^{-1}$ N:75 $mg \cdot L^{-1}$ P 18 days after seedling emergence. They found that the least dry leaf mass resulted from the water treatment and the greatest, resulted from transplants produced with 175 $mg \cdot L^{-1}$ N:75 $mg \cdot L^{-1}$ P treatment. Root development, however, was found to be promoted by high P and low to equal N concentration. The 292 $mg \cdot L^{-1}$ N:25 $mg \cdot L^{-1}$ P solution led to a significant decrease in leaf mass, plant mass and leaf area compared to the 175 $mg \cdot L^{-1}$ N:75 $mg \cdot L^{-1}$ P treatment. Karchi et al. concluded, therefore, that high N

with correspondingly low P levels had a negative effect on transplant growth.

Costigan and Mead (1987) reported that K concentrations in plants increased rapidly during the first few weeks of growth, and this made it very difficult to determine the critical level of K required for maximum growth rates. The percentage K in lettuce dry matter typically increases from 1 to 5 % within two weeks of sowing. Costigan and Mead performed sand culture experiments in the glasshouse to determine the internal K concentrations required by lettuce and cabbage transplants. They repeated the experiments with and without Na, since Na might affect K uptake by the plant. They grew lettuce and cabbage transplants in 14-cm diameter polypropylene plant pots containing 1 kg of sand, and irrigated with nutrient solutions. The solution K concentrations were varied by addition of different amounts of K_2SO_4. Before sowing, they wet the sand to saturation with nutrient solution. Once the plants emerged, they watered the pots daily with 150 mL of nutrient solution applied as a spray, followed by a short spray with water to rinse the leaves. They found that the critical levels for a 10 % reduction in plant growth rate were 2.2 % K for cabbage and 4.3 % K for lettuce. In the presence of Na, the corresponding critical levels were 0 and 1.0 % K. Costigan and Mead demonstrated that cabbage was more able to

substitute Na for K than was lettuce. They, however, concluded that in most practical situations, it was unlikely that plants would have access to large amounts of Na when K was limiting.

To summarize transplant fertilization research, N nutrition appears to be the driving force in lettuce transplant shoot growth (Tremblay and Senécal, 1988; Masson et al., 1991a). However, optimum amounts of N for shoots were not necessarily optimum for root growth. Increasing N increased shoot growth, but decreased root growth. Tremblay and Senécal (1988) obtained the largest lettuce transplant shoot mass with 350 compared with 150 $mg \cdot L^{-1}$ N, while Masson et al. (1991a) produced the largest shoots with 400 compared with 100 $mg \cdot L^{-1}$ N. In both cases, these amounts were the highest levels of N tested, and they were applied daily through overhead fertigation. Karchi et al. (1992), however, found that a proper combination of N and P was required to enhance lettuce transplant root growth. They produced the best transplants with either 175 $mg \cdot L^{-1}$ N and 75 $mg \cdot L^{-1}$ P or 58 $mg \cdot L^{-1}$ N and 126 $mg \cdot L^{-1}$ P. Potassium nutrition, on the other hand, did not appear to have any impact on lettuce transplant shoot and root growth.

Fertilizers can either be applied to transplants independent of irrigation, or they could be applied with the irrigation water (fertigation). When fertigation is

employed, careful management of fertilization is important since large amounts of fertilizers, especially N, could be applied when irrigation demands are high, especially where floatation irrigation is employed. If overfertilization occurs with floatation irrigation, there is no method to leach excessive salts.

Effect of Light on Lettuce Transplant Growth

Supplemental lighting of greenhouse-grown crops is not currently widely practiced in the United States (Decoteau and Friend, 1991). Only 5 % of the commercial greenhouse space in the United States is fitted with supplemental lighting systems (Thomas, 1990). Greenhouses with supplemental lighting systems are primarily used in ornamental crop production for prolonging the natural photoperiod during short days, supplemental light on overcast days, and night period interruption. Supplementary lighting has not been traditionally used in the production of vegetable transplants in the United States, and research on the effects of supplemental lighting on transplant development and subsequent yield performance is limited (Decoteau and Friend, 1991).

Sodium lamps were reported to be ideal for plant growing because of their durability, their favorable light

spectrum, and their high coefficient of conversion of electric energy into the energy of photosynthetically active radiation (Dullforce, 1971; Dennis and Dullforce, 1975; Tibbits et al., 1983).

Research has been reported on the effects of artificial lighting on the growth and morphology of the lettuce crop. However, according to Wurr et al. (1986), these have largely been observed on lettuce grown in a controlled environment (Soffe et al., 1977; Krizek and Ormond, 1980; Craker and Siebert, 1983), or under winter glasshouse conditions (Dennis and Dullforce, 1975) with butterhead lettuce. Wurr et al. (1986), therefore, conducted greenhouse and field experiments to determine the effects of supplementary lighting applied during transplant production, on lettuce transplant growth and maturity characters. They reported that in 1984, but not in 1985, tungsten lighting produced transplants with greater dry mass than the control. High-pressure sodium lighting had no effect on transplant mass in either year. Furthermore, in 1984 both lamp types gave rise to longer leaves than the control plants, but in 1985 this was only true for high-pressure sodium lighting.

Wurr et al. (1986) reported that in the field, inspite of lighting effects on transplant morphology, there were no effects in either year on lettuce mean head mass at maturity or the time from sowing to maturity. They concluded that

there was unlikely to be any benefit to growers in terms of increased head mass from providing supplementary lighting during transplant production, though it could be used early in spring to boost plant growth. However, they did not measure the effect of supplementary lighting on root growth.

Masson et al. (1991a) reported that supplementary lighting, 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ PAR, increased shoot dry mass of celery, lettuce, broccoli, and tomato transplants by 22 %, 40 %, 19 %, and 24 %, respectively. Supplementary lighting also improved the percentage of shoot dry matter for broccoli, tomato, and lettuce but not for celery. Tesi and Tallarico (1984) reported that an increase in the percentage of shoot dry matter improved cold resistance and that a quality tomato transplant should have > 10 % dry matter. Masson et al. (1991a) reported that leaf area for lettuce and broccoli transplants was increased under supplementary lighting, but no effect was detected for celery and tomato. Supplementary lighting lowered the specific leaf area (SLA) of celery, broccoli, and tomato, but not that of lettuce. Apparently, a low SLA is desirable since it was associated with greater leaf thickness. According to Masson et al. (1991a), under high photosynthetic photon flux density, the palisade layer cells generally elongated so that the leaves were thicker and a decrease in SLA was observed.

Supplementary lighting also reduced leaf area ratio (LAR) in celery, broccoli, and tomato transplants.

Masson et al. reported that transplant root dry mass of all plant species increased with 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ PAR supplementary lighting by 97 %, 42 %, 38 %, and 21 % for celery, lettuce, broccoli, and tomato, respectively. The root:shoot dry mass ratio (RSDMR) of celery and broccoli was increased by supplementary lighting. Lighting, however, did not affect this relationship for lettuce and tomato. Decreases in RSDMR caused by high N concentrations have been reported for several species (Dufault, 1985; Tremblay et al., 1987; Tremblay and Senécal, 1988; Weston and Zandstra, 1989). According to Masson et al. (1991a), this decrease was more evident for celery and lettuce under supplementary lighting.

Supplementary light at the transplant stage had no long-term effect on yield of celery or broccoli (Masson et al., 1991b). Supplementary lighting also did not influence lettuce yield or quality. Early yields of tomato transplants treated with supplementary lighting were higher on average than transplants produced under natural light alone. Cumulative tomato yields were, however, not affected by transplant lighting. Boivin et al., (1986) also obtained an increase of 31 % in the mass of marketable fruits in the first 3 weeks of harvest from greenhouse-grown tomato

transplants that had received supplementary light energy of 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ (PAR).

Basoccu and Nicola (1990), working with lettuce transplants, reported that, when natural light was decreased by 50 %, there was a decrease in percentage dry matter, fresh and dry mass, as well as number of leaves. In the field, lettuce head mass was increased by 18 % in plants which received natural light as opposed to those which received 50 % of the light during transplant production. A similar response was found with head diameter. According to Basoccu and Nicola, head diameter is influenced by the number of leaves present during transplanting.

Poniedzialek et al. (1988) studied the effect of controlled temperatures and light intensities on the shortening of the period of time in which lettuce transplants of good quality could be obtained. They found that supplementary light was decisive for shortening this time. The higher intensity of light, i.e. 40 $W \cdot m^{-2}$, shortened the period of production by 5 to 9 days compared with a lower intensity (20 $W \cdot m^{-2}$). A light intensity of 20 $W \cdot m^{-2}$ was found not be sufficient for adequate growth of plants and accounted for a pronounced prolongation of the period of production and an increased number of days with supplementary illumination. On the other hand, an increase in light intensity of 40 $W \cdot m^{-2}$ brought about a faster

increase in the area and number of leaves and in the content of dry matter and chlorophylls a and b.

To summarize, supplementary light seems to affect lettuce transplant quality only during greenhouse production. According to Poniedzialek et al. (1988) light intensity of 40 $W \cdot m^{-2}$ shortened the period of time in which lettuce transplants could be obtained. Shortening the period of lettuce transplant production could lead to lower transplant production costs. Furthermore, 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ PAR supplementary lighting increased lettuce transplant root mass (Masson et al., 1991a). An improvement in root growth is essential especially for lettuce transplants produced via floatation irrigation. Growers have had difficulty in producing lettuce transplants with sufficient root systems under floatation irrigation system. Perhaps the use of supplementary light could lead to faster production of lettuce transplants which could be more easily pulled from the transplant flats.

Effect of Temperature on Lettuce Transplant Growth

Lettuce is a cool season crop. According to Guzman (1990), mean temperatures between 11 and 19 °C enhance yield and quality in 'Great Lakes' types in California. In Florida, mean temperatures below 21 °C are conducive for

good yield and head quality. Furthermore, mean temperatures below 16 °C tend to delay maturity and, although internal quality of head is excellent, head size is reduced. Guzman further reported that for Florida cultivars such as 'South Bay' and 'Raleigh', temperatures of 4 °C practically caused growth to cease. Mean temperatures above 21 °C, on the other hand, tend to reduce lettuce yield and quality. According to Guzman, lettuce quality is affected by high temperature of long duration at any stage of growth, but that early exposure appears to have the most pronounced effect.

According to Sadler and Cantliffe (1990), lettuce grown from transplants is susceptible to premature flowering (bolting) when stressed by high temperature conditions in the greenhouse. Bolting can lead to total loss of crop or loss of lettuce quality due to elongated cores (stems), ribbiness of leaves, and loss of head compactness (density). Therefore, heat stress related problems, such as bolting, could offset the possible gains from transplanting lettuce. They grew 'Vanguard', a California cultivar known to bolt readily under high temperature conditions, and 'South Bay', a Florida cultivar highly resistant to bolting in growth chambers at 35/30, 30/25, 25/20, 20/20 °C day/night temperatures. They found that 'Vanguard' bolted about two weeks earlier than 'South Bay' when grown under high temperature conditions. Though the cultivars bolted at

different dates, those plants of each cultivar grown at the highest transplant temperatures bolted first, followed sequentially by those grown at the lower temperatures. They concluded that temperature at which the transplants are raised directly influenced the onset of bolting, regardless of temperatures in the field.

Guzman (1990) studied the effect of greenhouse temperature on lettuce transplant quality and field performance. Lettuce transplants were either grown in a cool, air-conditioned greenhouse, or in a warm greenhouse exposed to natural conditions. Day and night temperatures were not stated. In the cool greenhouse, mean temperatures were kept below 27 °C with relatively small fluctuations, while in the warm greenhouse, fall temperatures approached 38 °C for several hours each day. Guzman found that transplants grown for four weeks in a warm greenhouse were larger and more tender than those grown for four weeks in a cool greenhouse.

Guzman (1990) reported that there were significant reductions in plant stand in the fall season in Florida compared to winter, and indicated that high temperatures during transplanting in the fall were stressful to transplant growth. Yields in the fall were found to be, in general, lower than in winter. But in both fall and winter, lower yields and quality were more pronounced in treatments

exposed for longer periods to high temperatures during transplant production. The most obvious quality disorder was excessive head core length in the fall. Only transplants kept for four weeks in a cool greenhouse had acceptable core lengths. Excessive core length was due to high temperatures and long days in the warm greenhouse, but similar conditions appeared to have minimal effect on the winter crop. Guzman concluded that lower field temperatures following transplanting possibly nullified the high temperature effect during the transplant stage.

Poniedzialek et al. (1988) studied the effect of controlled temperatures and light intensities on the shortening of the production time for high quality lettuce transplants. They reported that an increase in day temperature from 15 to 22 °C accounted for a shortening of the period of growth of lettuce transplants. No significant differences were found in transplant fresh mass regardless of temperature. An interaction of light intensity and temperature was also observed. At higher intensity of supplementary illumination (40 $W \cdot m^{-2}$) the content of dry mass increased at a higher temperature, i.e. 22 °C. At a lower intensity of light (20 $W \cdot m^{-2}$) an increase of temperature from 15 to 22 °C was insignificant. Also, in plants grown at a higher temperature of 22 °C without

supplementary lighting, the content of chlorophylls a and b was reduced considerably.

To summarize, temperature has a major effect on lettuce growth, both in the greenhouse and field conditions. Transplants produced under temperatures of 30 °C or higher, tend to bolt readily in the field (Sadler and Cantliffe, 1990). Furthermore, such transplants produced lower yields and poor internal quality in the field (Guzman, 1990). However, according to Guzman (1990) and Sadler and Cantliffe (1990), if transplants are produced at temperatures below 27 °C, they can to a certain extent, overcome the problem of premature bolting of lettuce plants. Improved growth of lettuce transplants was also reported when plants were produced under 22 °C than under 15 °C (Poniedzialek et al. (1988). The higher temperature in combination with supplementary light led to shortening of the time needed to produce lettuce transplants of good quality.

Conclusions

Any beneficial effects of N, P, and K nutrition, irrigation, light, and temperature on lettuce transplant growth should be judged according to a predetermined standard for lettuce transplant quality. High quality or ideal transplants have enough roots to fill a tray cell to

enable plants to be easily pulled from the transplant flat, and maximize water and nutrient absorption. Shoots which are too large and stretched are not ideal since transplants could easily be damaged during transplanting.

Fertilizers can either be applied to plants independent of irrigation, or they could be applied with the irrigation water (fertigation), such as is the case with floatation (sub-) irrigation. Nitrogen has been found to be the element with the largest impact on lettuce transplant shoot growth. In studies where floatation irrigation was used, it was important to manage both N and fertigation frequency. During periods of high irrigation demands, frequent fertigation with low concentrations of N would be required to minimize excessive shoot growth.

Extension of photoperiod and increasing the light intensity with supplementary light could be beneficial to lettuce transplants by improving root growth. Similarly for temperature, production of quality transplants could be ensured by cooling or warming the greenhouse to optimize growing conditions.

CHAPTER 3

PHOSPHORUS REQUIREMENTS FOR LETTUCE TRANSPLANT GROWTH USING A FLOATATION IRRIGATION SYSTEM

Introduction

Vegetable transplants grown in plug cells require careful management of fertilizers (Dufault and Waters, 1985; Weston, 1988) due to limited volume in the cell and high seedling densities. Concentrations of essential plant nutrient elements within media are frequently insufficient to sustain plant growth for an extended period due to frequent irrigation requirements (Garton and Widders, 1990). Production of vigorous seedlings is a prerequisite to a successful crop, especially in lettuce where the period of containerized transplant growth comprises up to 30 % of the cropping time (Karchi and Cantliffe, 1992). Improved nutrient regimes would contribute to efficient development of quality transplants (Tremblay and Senécal, 1988).

The role of P in transplant growth has been investigated in a number of vegetable crops. In celery, increasing the P concentration from 5 to 125 $mg \cdot L^{-1}$

increased transplant diameter and height, shoot and root mass, and leaf area (Dufault, 1985). In tomato, increasing P from 5 to 45 $mg \cdot L^{-1}$ increased transplant height, stem diameter, leaf number, leaf area, and fresh shoot mass, but not dry shoot or root mass (Melton and Dufault, 1991). Dufault and Schultheis (1994) reported that increasing P from 5 to 45 $mg \cdot L^{-1}$ increased fresh and dry shoot mass, leaf area, and leaf count in combination with 75 or 225 $mg \cdot L^{-1}$ N, but not with 25 $mg \cdot L^{-1}$ N. Phosphorus at 5, 15, or 45 $mg \cdot L^{-1}$ did not influence dry root mass.

Data are lacking on the response of lettuce transplant roots and shoots to frequent P applications using a floatation irrigation system. In this system, nutrients are supplied with each irrigation by floating flats directly in nutrient solution. Growers using this system have been unable to produce lettuce transplants with sufficient roots in a tray cell to enable easy removal of transplants from the transplant flat (Robles, personal communication). Perhaps, optimizing P fertilization practices could lead to improved root development in lettuce transplants.

In the present investigation, a range of P concentrations were supplied via floatation irrigation to determine the P requirements for production of easy-to-pull transplants, which would rapidly establish in the field.

Materials and Methods

Greenhouse Experiments

'South Bay' lettuce transplants were grown in a glass greenhouse at the University of Florida, Gainesville, FL. Speedling styrofoam planter flats, model F392A [392 cells of 1.9 × 1.9 × 6.3 cm; 10.9 cm^3 (length × width × depth; volume)], were used for growing plants. A peat+vermiculite+styrofoam bead mix (1:2:1, v/v/v), with AquaGro wetting agent (Aquatrols, Cherry Hill, NJ) at 0.2 $kg \cdot m^{-3}$, was used for media. Three experiments were conducted (Table 3-1). The plants were grown with natural photoperiod

Table 3-1. Sowing schedule and initial media test (Hanlon et al., 1994) for Experiments 1 to 3.

Expt	Sowing date	Media test[z]						
		pH	EC	NO_3-N	P	K	Ca	Mg
			($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)				
1	17 Jun 1993	4.7	0.9	1.3	12.4	14.6	14.2	11.6
2	18 Sep 1995	4.5	0.6	0	0.6	46.2	6.3	22.2
3	31 Jan 1996	5.2	0.2	0.3	0.4	24.4	0.6	5.8

[z]Concentrations in the saturated paste extract.

extended to 16 h by 1000-W, high-pressure sodium lamps (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux). A record of cloud cover was kept as an indication of the evaporative demand of the atmosphere. Greenhouse air temperature just above the plant canopy, and media temperatures were recorded by a

Series 3020T Datalogger (Electronic Controls Design, Inc., Mulino, OR). The flats were seeded, then covered with a thin layer of vermiculite, overhead irrigated enough to moisten the vermiculite, and transferred to a cooler at 20 °C for germination. After 48 h, flats were returned to the greenhouse.

Plants in Experiments 1 and 2 were irrigated every two to four days, depending on water needs, by floating flats in nutrient solution containing P at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ as Na_2HPO_4. Other nutrients were supplied at equivalent rates to all plants and consisted of (in $mg \cdot L^{-1}$) 100 N, 30 K, 100 Ca, and half-strength Hoagland's solution for micronutrients only (Hoagland and Arnon, 1950), which was comprised of Mg, S, B, Cu, Cl, Mo, and Zn. In Experiment 2, the Ca level was reduced from 100 to 30 $mg \cdot L^{-1}$.

Plants in Experiment 3 were irrigated every second day by floating flats in nutrient solution containing P at 0, 15, 30, 60, or 90 $mg \cdot L^{-1}$ in factorial combination with N at 60 or 100 $mg \cdot L^{-1}$. Phosphorus was supplied from Na_2HPO_4, while N was supplied from NH_4NO_3. Other nutrients were supplied as described above.

Experiments 1 and 2 were arranged in a randomized complete-block design with 5 treatments and 4 replications. Experiment 3 was a randomized complete-block design with 10

treatments consisting of a factorial combination of 5 levels of P and 2 levels of N, replicated four times.

Plant samples, 5 per treatment, were taken at 14, 21, and 28 days after sowing (DAS) for growth measurements. Measurements included shoot and root fresh and dry mass, and leaf area (measured by a LI-3100 leaf area meter; LI-COR, Lincoln, NE). Growth variables calculated were: root:shoot ratio (RSR = dry root mass ÷ dry shoot mass), relative growth rate (RGR = [ln (final total dry mass) - ln (initial total dry mass) ÷ (final time - initial time)]), net assimilation rate (NAR = [(final total dry mass - initial total dry mass) ÷ (final time - initial time) × {(ln (final leaf area) - ln (initial leaf area)} ÷ (final leaf area - initial leaf area)]), specific leaf area (SLA = leaf area ÷ dry shoot mass), leaf area ratio (LAR = leaf area ÷ total dry mass), leaf mass ratio (LMR = dry shoot mass ÷ total dry mass), and root mass ratio (RMR = dry root mass ÷ total dry mass) (Hunt, 1978; 1982; Dubik et al., 1992).

At the last sampling date in Experiments 2 and 3, fresh roots were scanned with a Hewlett Packard desktop scanner and analyzed with MacRHIZO software (Regent Instruments Inc., Quebec, Canada) at 300 dpi for length, area, and diameter. Additionally, pull force, the force required to pull a lettuce transplant out of a flat using Model DPP Dial Push-Pull Gauge (John Chatillon and Sons, Kew Gardens, NY)

attached to a binder clip, was measured. Pulling success was calculated as the percentage of 5 plants per treatment that could be pulled out of the flats without any breakage.

Dry shoot samples from the last sampling dates were ground to pass a 20-mesh screen and dry-ashed for P or acid-digested for total Kjeldahl N according to Wolf (1982). For total P determination, 0.5 g subsamples were weighed into 10 mL beakers. The samples were then dry-ashed in a muffle furnance at 500 °C for 10 h. The ash was moistened with 1 N HCl, poured into 50 mL volumetric flasks, and brought to volume with 1 N HCl. The solutions were filtered through 'Q8' filter papers (Fisher brand), with a particle retention of > 10 μm, into 25 mL scintillation vials. The solution samples were sent to the Analytical Research Laboratory, University of Florida, and analyzed with Model 61-E Inductively Coupled Plasma Spectrometry (Thermo Jarrell Ash Corporation, Franklin, MA).

The acid digestion procedure consisted of weighing 0.25 g subsamples into 50 mL digestion tubes. Sulfuric acid and 30 % hydrogen peroxide were added to the tubes that were then heated on a digestion block at 375 °C. After the digestion process was completed (a total of 2.5 h), the samples were allowed to cool, and deionized water was used to bring the volume to 25 mL. The solutions were filtered through 'P8' filter papers (Fisher brand), with a particle

retention of > 25 μm, into 25 mL scintillation vials. The solution samples were sent to the Analytical Research Laboratory, University of Florida, and N was determined on a 300 Series Rapid Flow Analyzer (ALPKEM Corporation, Wilsonville, OR).

Data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

Field Experiments

Plants from each treatment in Greenhouse Experiments 2 and 3 were transplanted into an Arredondo fine sandy soil (loamy, siliceous, hyperthermic Grosarenic Paleudults) in beds covered with white-on-black polyethylene-mulch (0.038 mm thick) at the University of Florida Horticultural Unit, Gainesville (Table 3-2). Experiment 1 was a randomized complete-block design with 5 treatments and 4 replications. Experiment 2 was a randomized complete-block design, with 10 treatments consisting of a factorial combination of 5 levels of P and 2 levels of N, replicated 4 times. Preplant fertilizer (13N-0P-10.8K) was applied broadcast and incorporated in the bed at 230 $kg \cdot ha^{-1}$. Raised beds spaced 1.2 m center to center, were fumigated with methyl bromide and then covered with the polyethylene mulch. There were 30

Table 3-2. Transplanting schedule and initial soil test (Hanlon et al., 1994) for Experiments 1 and 2.

Experiment	Transplanting date	Soil test[z]					
		pH	EC	P	K	Ca	Mg
			($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)			
1	17 Oct 1995	5.9	0.1	185	30	733	54
2	29 Feb 1996	5.8	0.0	247	37	695	43

[z]pH and EC determined on 2:1 water to soil ratio procedure, while elements are from a Mehlich-1 extractant.

plants per plot planted on double offset rows with a spacing of 0.3 m between plants and between rows on the bed (equivalent to 54,000 plants per ha).

Just after transplanting, 100 mL of nutrient solution (150 $mg \cdot L^{-1}$ 20N-8.6P-16.7K) was applied to each transplant hole as a starter fertilizer. Water was applied twice daily for 20 min each cycle, using drip irrigation lines placed on the center of the bed with emitters spaced 0.3 m apart. Tensiometers (Irrometer Company, Inc., Riverside, CA) were used to monitor soil moisture adequacy in the beds. The root zone area was maintained at approximately -10 kPa according to Hochmuth and Clark (1991). Starting one week after transplanting, fertilizer at a rate of 15 $kg \cdot ha^{-1}$ N and 16 $kg \cdot ha^{-1}$ K, supplied from NH_4NO_3 and KNO_3, was injected once weekly using a venturi pump (Netafim Irrigation, Altamonte Springs, FL), with the last application one week before harvest to give a total amount of 150 $kg \cdot ha^{-1}$ N and 180

$kg \cdot ha^{-1}$ K. Cultural management practices were similar to those used commercially in Florida (Hochmuth et al., 1988).

At head maturity, the center 20 plants in a plot were cut, weighed individually, and then 10 heads were assessed for firmness, cut longitudinally for height, diameter, stem width, and core length measurements. Wrapper leaves were sampled at harvest and analyzed for total P and Kjeldahl N as previously described for Greenhouse Experiments. Field data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, Inc, Cary, NC). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

Results and Discussion

Greenhouse Experiments

Experiment 1 was conducted during the summer, under greenhouse temperatures ranging from 21 to 37 °C (Fig. 3-1). The average daily maximum media temperature was 31 °C, while the average daily minimum media temperature was 22 °C. During the course of the trial, there were totals of 6 cloudy and 23 sunny days. Six of the sunny days were followed with rain in the afternoon.

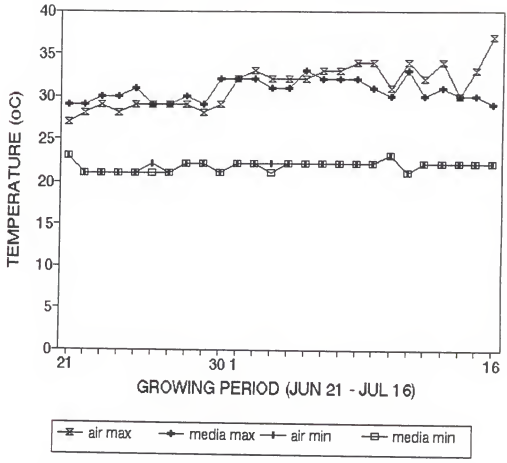


Fig. 3-1. Maximum and minimum air and media temperature during transplant production for Experiment 1, Jun/Jul 1993.

Fresh shoot and root mass, and leaf area, were not determined at 15 days after sowing (DAS). For plants sampled 15 DAS, there was a positive linear response of dry shoot mass to applied P (Table 3-3). The major increase in dry shoot mass to applied P occurred between 0 and 15 $mg \cdot L^{-1}$. For plants sampled 21 and 29 DAS, fresh and dry shoot mass increased in quadratic fashion to applied P. At any level of applied P, fresh and dry shoot mass were improved compared to 0 P. For plants sampled 15 DAS, dry root mass responded in quadratic fashion to applied P, and was greatest with 0 P. However, for plants sampled 21 and 29 DAS, applied P did not influence fresh and dry root mass. For plants sampled 21 and 29 DAS, leaf area increased in quadratic fashion to applied P, and was least with 0 P. Leaf tissue P increased in quadratic fashion, implying that P did not affect root growth.

Root:shoot ratios decreased in quadratic fashion in response to P, regardless of sampling date. The greatest RSR values were obtained with 0 P, while there were similar RSR values in plants grown with 15 to 60 $mg \cdot L^{-1}$ P. Plants grown with 0 P had the greatest RSR values because shoots were smaller compared to plants grown with any level of P, while root growths were similar among all plants.

Table 3-3. Root and shoot characteristics of lettuce transplants as affected by P nutrition for Experiment 1, June/July 1993.

Phosphorus applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf tissue P ($g \cdot kg^{-1}$)	Root: shoot ratio
		15 Days After Sowing					
0		12.4		3.8			0.31
15		16.5		3.2			0.20
30		15.6		3.5			0.22
45		15.3		2.9			0.19
60		16.5		3.2			0.20
Response		L**		Q**			L*
		21 Days After Sowing					
0	355	28.0	155	12.0	12.9		0.43
15	688	40.6	169	11.9	26.1		0.29
30	781	45.6	176	12.4	29.3		0.27
45	741	43.4	179	12.7	28.6		0.30
60	736	45.1	189	13.2	30.2		0.30
Response	Q**	Q**	NS	NS	Q**		Q**
		29 Days After Sowing					
0	685	58.0	304	25.3	25.0	1.2	0.44
15	1268	85.4	307	23.8	46.8	3.0	0.29
30	1297	85.6	301	23.8	48.1	4.2	0.28
45	1401	92.3	320	24.7	50.3	4.6	0.27
60	1297	89.8	341	26.6	48.5	4.6	0.30
Response	Q**	Q**	NS	NS	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

For plants grown to 21 DAS, there was a positive linear increase in RGR values in response to applied P (Table 3-4). For plants grown to 29 DAS, RGR values were not influenced by P and were lower than for plants grown to 21 DAS, implying that P was more important earlier in growth. Greater RGR values for plants grown to 21 compared to 29 DAS meant that younger plants had higher efficiency for growth than older ones. For plants grown to 29 DAS, NAR decreased in quadratic fashion in response to applied P. The production of dry matter per unit leaf area (NAR) was greater in plants grown with 0 P, but the total production of dry matter over the same period was greater with any level of P.

For plants sampled 21 and 29 DAS, SLA and LAR increased in quadratic fashion in response to applied P. Lowest SLA and LAR values were obtained with 0 P, while there were similar values with any other level of P. The reduction in SLA and LAR values for plants grown with 0 P reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

For plants sampled 15 DAS, both LMR and RMR values were not affected by P. For plants sampled 21 and 29 DAS, LMR values increased in quadratic fashion, while RMR values decreased in quadratic fashion in response to applied P. For plants grown to 29 DAS, approximately 70 % of the dry matter

Table 3-4. Influence of P nutrition on growth characteristics of lettuce transplants for Experiment 1, June/July 1993.

Phosphorus applied ($mg \cdot L^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			15 Days After Sowing			
0					0.76	0.24
15					0.84	0.16
30					0.82	0.18
45					0.84	0.16
60					0.83	0.17
Response					NS	NS
			21 Days After Sowing			
0	0.89		0.46	0.32	0.70	0.30
15	0.97		0.64	0.49	0.77	0.23
30	1.11		0.64	0.51	0.79	0.21
45	1.13		0.66	0.51	0.77	0.23
60	1.08		0.67	0.52	0.77	0.23
Response	L**		Q**	Q**	Q**	Q**
			29 Days After Sowing			
0	0.73	2.36	0.43	0.30	0.70	0.30
15	0.74	1.65	0.55	0.43	0.78	0.22
30	0.64	1.36	0.56	0.44	0.78	0.22
45	0.74	1.59	0.55	0.43	0.79	0.21
60	0.69	1.53	0.54	0.42	0.77	0.23
Response	NS	Q*	Q**	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

was allocated to shoots and 30 % allocated to roots in lettuce transplants grown with 0 P. Plants grown with 15 to 60 $mg \cdot L^{-1}$ P allocated about 78 % of dry matter to shoots, with only 22 % to roots. With added P, more dry matter was, therefore, partitioned to shoots rather than to roots.

The results of Experiment 1 indicated that high quality transplants could be produced without added P, when the peat+vermiculite media had at least 12 $mg \cdot kg^{-1}$ P (water extractable) before any fertilizer applications.

In order to further test this conclusion, Experiment 2 was conducted during the fall, instead of summer, under greenhouse temperatures ranging from 18 to 46 °C (Fig. 3-2). The average daily maximum media temperature was 33 °C, while the average daily minimum media temperature was 26 °C. During the course of the experiment, there were 12 sunny days with two of the days resulting in afternoon showers, and 16 cloudy days with rain during four of the days.

For plants sampled 13, 21, and 28 DAS, fresh and dry shoot mass increased in quadratic fashion in response to applied P (Table 3-5). The major responses of shoot mass to applied P occurred between 0 and 15 $mg \cdot L^{-1}$, regardless of sampling date. For plants sampled 13 DAS, fresh and dry root mass were unaffected by P. For plants sampled 21 and 28 DAS, there was a positive linear increase in fresh and dry root mass in response to applied P. For plants grown to 28 DAS,

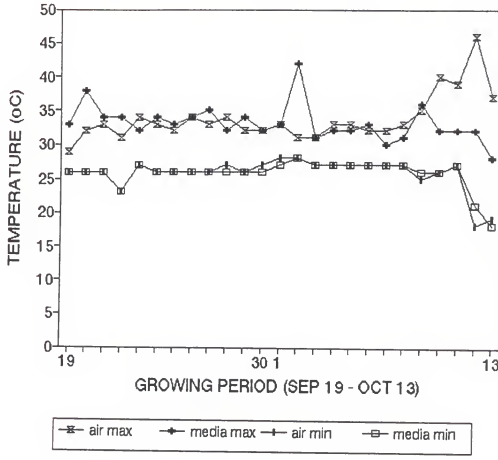


Fig. 3-2. Maximum and minimum air and media temperature during transplant production for Experiment 2, Sep/Oct 1995.

Table 3-5. Root and shoot characteristics of lettuce transplants as affected by P nutrition for Experiment 2, September/October 1995.

Phosphorus applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Root length (cm)	Root area (cm^2)	Root diameter (mm)	Leaf area (cm^2)	Pull force (N)	Pulling success (%)
				13 Days After Sowing						
0	118	7.4	52	2.9				5.0		
15	259	11.9	53	2.9				11.0		
30	281	12.6	57	3.1				12.1		
45	288	12.7	56	3.2				12.2		
60	279	12.7	55	3.1				11.9		
Response	Q**	Q**	NS	NS				Q**		
				21 Days After Sowing						
0	465	28.1	176	11.9				15.2		
15	1276	60.2	222	14.0				41.8		
30	1385	59.8	215	12.5				43.7		
45	1353	61.2	242	15.2				43.1		
60	1365	63.3	243	14.8				43.0		
Response	Q**	Q**	L**	L*				Q**		
				28 Days After Sowing						
0	762	58.9	245	19.1	246	24.4	0.32	25.2	0.019	30
15	2080	113.9	293	21.0	271	27.9	0.33	66.3	0.021	95
30	2076	111.7	298	20.8	275	27.3	0.32	66.4	0.019	90
45	2067	116.9	329	22.8	305	30.6	0.32	65.5	0.019	85
60	2115	117.9	344	23.7	310	31.5	0.32	67.1	0.020	90
Response	Q**	Q**	L**	L*	L**	L**	NS	Q**	NS	Q*

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

root length and area increased in linear fashion in response to applied P, but root diameter was unaffected by P. Leaf area increased in a quadratic fashion to applied P, regardless of sampling date. Phosphorus application to the media did not affect pull force, but improved pulling success from 30 % to approximately 90 %. Most of the P effect occurred between 0 and 15 $mg \cdot L^{-1}$ P. In Chapter 6, pull force was related to pulling success, but this was not so in the present work probably because there were smaller differences in root mass among the treatments in the present investigation.

For plants sampled 28 DAS, leaf tissue P increased in quadratic fashion to applied P, from about 1 to 6 $g \cdot kg^{-1}$ (Table 3-6). Root:shoot ratios decreased in quadratic fashion in response to applied P, regardless of sampling date. The largest RSR values were obtained with 0 P. Root:shoot ratios were similar with all P treatments within sampling date.

For plants grown to 21 DAS, RGR increased in linear fashion to applied P, while for plants grown to 28 DAS, RGR was not affected by P. Therefore, P appears to once again be more important earlier in plant growth than later on. For plants grown to 21 or 28 DAS, NAR decreased in a quadratic fashion to applied P. Net assimilation rate was greatest with 0 P regardless of sampling date, but the total

Table 3-6. Influence of P nutrition on growth characteristics of lettuce transplants for Experiment 2, September/October 1993.

Phosphorus applied ($mg \cdot L^{-1}$)	Leaf tissue P ($g \cdot kg^{-1}$)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
				13 Days After Sowing				
0		0.40			0.68	0.49	0.72	0.28
15		0.25			0.92	0.74	0.80	0.20
30		0.25			0.96	0.77	0.80	0.20
45		0.25			0.97	0.77	0.80	0.20
60		0.25			0.94	0.75	0.80	0.20
Response		Q*			Q**	Q**	Q*	Q*
				21 Days After Sowing				
0		0.43	1.36	3.25	0.54	0.38	0.70	0.30
15		0.23	1.61	2.58	0.70	0.56	0.81	0.19
30		0.21	1.52	2.31	0.73	0.61	0.83	0.17
45		0.25	1.57	2.47	0.71	0.56	0.80	0.20
60		0.23	1.59	2.57	0.68	0.55	0.81	0.19
Response		Q**	L*	Q**	Q**	Q**	Q**	Q**
				28 Days After Sowing				
0	1.2	0.33	0.67	1.92	0.43	0.32	0.75	0.25
15	3.5	0.18	0.60	1.14	0.58	0.49	0.85	0.15
30	5.5	0.19	0.60	1.11	0.60	0.50	0.84	0.16
45	5.8	0.19	0.60	1.17	0.56	0.47	0.84	0.16
60	6.2	0.20	0.60	1.18	0.57	0.48	0.83	0.17
Response	Q**	Q**	NS	Q**	Q**	Q**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

production of dry matter over the same period was greater with any level of P.

For plants sampled 13, 21, and 29 DAS, SLA and LAR increased in quadratic fashion to applied P. Lowest SLA and LAR values were obtained with 0 P, while there were similar values with any level of P. The reduction in SLA and LAR values for plants grown with 0 P reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

For plants sampled 13, 21, and 29 DAS, LMR values increased in quadratic fashion, while RMR values decreased in quadratic fashion in response to applied P. For plants grown to 28 DAS, approximately 75 % of the dry matter was allocated to shoots and 25 % allocated to roots in lettuce transplants grown with 0 P. Plants grown with 15 to 60 mg $P \cdot L^{-1}$ allocated about 84 % of dry matter to shoots, with only 16 % to roots. Once again, added P caused more dry matter to be partitioned to shoots rather than to roots, and more so for transplants in the present experiment than in the summer grown ones.

In Experiment 2, high quality transplants were produced with 15 to 60 $mg \cdot L^{-1}$ P. Although transplants grown with 0 P had greater RSR, NAR, and RMR values, they were inferior to transplants grown with any other level of P because they could not be easily pulled from the transplant flat. A

reason why plant roots responded more to applied P in this experiment but not in Experiment 1, might be due to lower initial P levels in the media in this experiment (0.6 $mg \cdot kg^{-1}$) compared to Experiment 1 (12.4 $mg \cdot kg^{-1}$).

In the previous two experiments, 100 $mg \cdot L^{-1}$ N was used when growing transplants at various levels of P. Subsequent studies with N in Chapter 6, however, revealed that optimum N for lettuce transplant root growth might be in the 60 $mg \cdot L^{-1}$ range or less, supplied every second day through floatation irrigation. Therefore, in Experiment 3, N was included as a variable to compare 60 versus 100 $mg \cdot L^{-1}$ N concentration at selected levels of P. Furthermore, the highest level of P was increased from 60 to 90 $mg \cdot L^{-1}$, since in Experiment 2 root mass may not have reached greatest level with an application rate of 60 $mg \cdot L^{-1}$ P.

Experiment 3 was conducted during the winter, under greenhouse temperatures ranging from 14 to 38 °C (Fig. 3-3). The average daily maximum media temperature was 29 °C, while the average daily minimum media temperature was 21 °C. During the course of the experiment, there were a total of 17 sunny and 9 cloudy days.

For plants sampled 15 and 22 DAS, there were no P and N interactions for dry shoot mass (Table 3-7). By both sampling dates, dry shoot mass increased in quadratic fashion in response to applied P. The major increase in dry

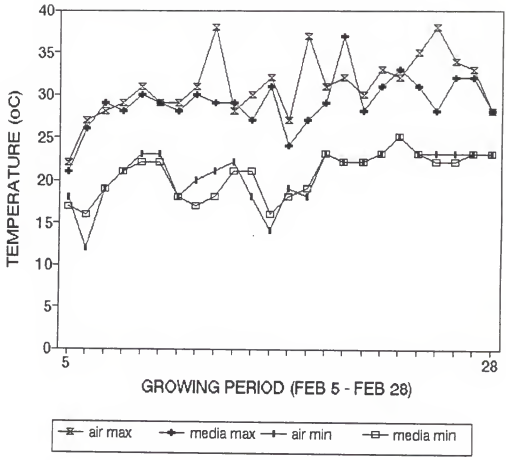


Fig. 3-3. Maximum and minimum air and media temperature during transplant production for Experiment 3, February 1996.

Table 3-7. Root and shoot characteristics of lettuce transplants as affected by P and N nutrition for Experiment 3, Feb 1996.

Nutrient applied	Dry shoot mass[z]	Dry root mass	Root length	Root area	Root diameter	Leaf area	
($mg \cdot L^{-1}$)	(mg)	(mg)	(cm)	(cm^2)	(mm)	(cm^2)	
		15 Days After Sowing					
P							
0	4.0	2.8				2.3	
15	9.0	2.8				6.9	
30	9.6	3.0				7.4	
60	10.2	3.0				8.0	
90	10.2	2.9				8.1	
Response	Q**	NS				Q**	
N							
60	8.4	3.0				6.4	
100	8.8	2.7				6.7	
Response	NS	*				NS	
P × N	NS	NS				NS	
		22 Days After Sowing					
P						N_1	N_2
0	9.8	6.6				3.6	3.4
15	42.3	14.7				26.1	32.7
30	46.1	15.3				27.6	36.4
60	47.1	15.5				28.3	38.3
90	46.7	15.5				27.6	37.9
Response	Q**	Q**				Q**	Q**
N							
60	35.8	14.0					
100	41.0	13.0					
Response	**	*					
P × N	NS	NS				**	
		28 Days After Sowing					
P	N_1 N_2					N_1	N_2
0	12.7 12.1	8.6	94	8.4	0.28	4.2	4.2
15	82.1 104.7	24.5	282	26.7	0.30	48.4	68.1
30	83.5 105.6	23.9	276	26.0	0.30	50.3	70.6
60	82.8 104.4	24.4	306	29.5	0.31	55.0	69.9
90	81.0 101.6	25.4	292	27.0	0.29	49.0	70.6
Response	Q** Q**	Q**	Q**	Q**	Q**	Q**	Q**
N							
60		23.2	255	24.2	0.30		
100		19.5	245	22.9	0.30		
Response		**	NS	NS	NS		
P × N	**	NS	NS	NS	NS	**	

[z]N_1 = 60 $mg \cdot L^{-1}$; N_2 = 100 $mg \cdot L^{-1}$.
Quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

shoot mass to P occurred between 0 and 15 $mg \cdot L^{-1}$. Dry shoot mass was not influenced by N for plants sampled 15 DAS. For plants sampled 22 DAS, dry shoot mass was greater in plants grown with 100 than with 60 $mg \cdot L^{-1}$ N. For plants sampled 28 DAS, dry shoot mass increased in quadratic fashion to applied P at both levels of N. Nitrogen had no influence on dry shoot mass, but dry shoot mass was increased with all levels of applied P. With 100 $mg \cdot L^{-1}$ N, the response of dry shoot mass to P was greater than with 60 $mg \cdot L^{-1}$ N.

Nitrogen did not interact with P to influence dry root mass, regardless of sampling date (Table 3-7). For plants sampled 15 DAS, applied P did not influence dry root mass. Root mass was less in plants grown with 100 than 60 $mg \cdot L^{-1}$ N. For plants sampled 22 and 28 DAS, dry root mass increased in quadratic fashion in response to applied P. The major root response to P was between 0 and 15 $mg \cdot L^{-1}$. Root mass accumulation was adversely affected by increased N by both sampling dates. For plants grown to 28 DAS, root length, area, and diameter increased in quadratic fashion in response to applied P. The smallest root length, area, and diameter were obtained with 0 P. Applied N did not influence any of the measured root parameters.

For plants sampled 15 DAS, there were no P by N interactions for leaf area which increased in quadratic fashion in response to applied P. Applied N did not

influence leaf area by this sampling date. For plants sampled 22 and 28 DAS, leaf area increased in quadratic fashion to applied P, regardless of N concentration applied. Nitrogen had no influence on leaf area, but leaf area was increased at all levels of applied P. With 100 $mg \cdot L^{-1}$ N, the response of leaf area to P was greater than with 60 $mg \cdot L^{-1}$ N.

For plants grown to 28 DAS, there were no P by N interactions for leaf tissue N (Table 3-8). Leaf tissue N decreased in quadratic fashion in response to applied P. The response was probably a dilution effect since transplants were larger at any level of P compared to 0 P. Plants grown with 100 $mg \cdot L^{-1}$ N had more N concentration in the leaves than those grown with 60 $mg \cdot L^{-1}$ N. Leaf tissue P increased in quadratic fashion to applied P, regardless of N applied. Nitrogen had no influence on leaf tissue P at 0 or 15 $mg \cdot L^{-1}$ P, but it was increased with all other levels of applied P. With 100 $mg \cdot L^{-1}$ N, the response of leaf tissue P to applied P was greater than with 60 $mg \cdot L^{-1}$ N.

For plants sampled 15 and 28 DAS, there were no P by N interactions for RSR. Root shoot ratios decreased in quadratic fashion in response to applied P. The largest RSR values were obtained with 0 P, while the smallest RSR values were obtained with all levels of applied P. Plants grown with 60 $mg \cdot L^{-1}$ N had larger RSR values than those grown with

Table 3-8. Influence of P and N nutrition on growth characteristics of lettuce transplants for Experiment 3, February 1996.

Nutrient applied ($mg \cdot L^{-1}$)	Leaf tissue N ($g \cdot kg^{-1}$)	Leaf tissue P[z] ($g \cdot kg^{-1}$)		Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)
15 Days After Sowing						
P						
0				0.69		
15				0.31		
30				0.31		
60				0.29		
90				0.29		
Response				Q**		
N						
60				0.40		
100				0.36		
Response				*		
P × N				NS		
22 Days After Sowing						
			N_1	N_2		
P						
0			0.66	0.69	0.90	3.38
15			0.37	0.32	1.58	2.91
30			0.39	0.28	1.59	2.92
60			0.36	0.30	1.56	2.83
90			0.37	0.29	1.56	2.80
Response			Q**	Q**	Q**	Q*
N						
60					1.41	3.09
100					1.46	2.85
Response					NS	*
P × N				*	NS	*NS*
28 Days After Sowing						
		N_1	N_2			
P						
0	48.5	0.9	1.0	0.70	0.25	1.23
15	24.6	3.8	4.0	0.27	0.73	1.46
30	23.5	4.8	5.9	0.26	0.66	1.30
60	22.7	5.1	7.4	0.27	0.64	1.21
90	22.1	5.8	8.6	0.29	0.63	1.23
Response	Q**	Q**	Q**	Q**	Q**	NS
N						
60	24.7			0.40	0.56	1.33
100	31.8			0.31	0.61	1.25
Response	**			**	NS	NS
P × N	NS		**	NS	NS	NS

[z]N_1 = 60 $mg \cdot L^{-1}$; N_2 = 100 $mg \cdot L^{-1}$.
Quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

100 mg $N \cdot L^{-1}$. For plants sampled 22 DAS, N had no influence on RSR values, but RSR values were decreased with all levels of applied P. With 100 mg $\cdot L^{-1}$ N, the response of RSR to P was greater than with 60 mg $\cdot L^{-1}$ N, because added N favored shoot growth rather than root growth.

For plants grown to 22 or 28 DAS, there were no P by N interactions for RGR and NAR (Table 3-8). By both sampling dates, RGR values increased in quadratic fashion in response to applied P. Nitrogen did not influence RGR values. For plants grown to 22 DAS, NAR values decreased in quadratic fashion in response to applied P. The greatest NAR values were obtained with 0 P, and the least with 90 mg $\cdot L^{-1}$ P. Net assimilation rate was greater with 60 than 100 mg $\cdot L^{-1}$ N. By 28 DAS, P and N did not influence NAR values.

For plants sampled 15 and 28 DAS, there were no P by N interactions for SLA (Table 3-9). By both sampling dates, SLA values increased in quadratic fashion in response to applied P. Most of the response of SLA to applied P occurred between 0 and 15 mg $\cdot L^{-1}$. For plants sampled 15 DAS, applied N did not influence SLA, while for plants sampled 28 DAS, SLA was improved by 100 compared to 60 mg $\cdot L^{-1}$ N. For plants sampled 22 DAS, SLA values increased in quadratic fashion in response to applied P, regardless of N added. Specific leaf area increased in plants fertilized with 60 mg $\cdot L^{-1}$ N when P

Table 3-9. Influence of P and N nutrition on growth characteristics of lettuce transplants for Experiment 3, February 1996.

Nutrient applied	Specific leaf area[z]	Leaf area ratio	Leaf mass ratio	Root mass ratio
($mg \cdot L^{-1}$)	($cm^2 \cdot mg^{-1}$)	($cm^2 \cdot mg^{-1}$)		
		15 Days After Sowing		
P				
0	0.58	0.34	0.59	0.41
15	0.77	0.59	0.76	0.24
30	0.77	0.59	0.76	0.24
60	0.78	0.60	0.77	0.23
90	0.80	0.62	0.78	0.22
Response	Q**	Q**	Q**	Q**
N				
60	0.74	0.54	0.72	0.28
100	0.74	0.56	0.75	0.25
Response	NS	NS	**	**
P × N	NS	NS	NS	NS
		22 Days After Sowing		
P	N_1 N_2	N_1 N_2	N_1 N_2	N_1 N_2
0	0.35 0.37	0.21 0.22	0.60 0.59	0.40 0.41
15	0.67 0.72	0.49 0.54	0.73 0.76	0.27 0.24
30	0.66 0.72	0.48 0.56	0.72 0.78	0.28 0.22
60	0.64 0.77	0.47 0.59	0.73 0.77	0.27 0.23
90	0.63 0.76	0.46 0.59	0.73 0.77	0.27 0.23
Response	Q** Q**	Q** Q**	Q** Q**	Q** Q**
N				
60				
100				
Response				
P × N	**	**	**	**
		28 Days After Sowing		
P		N_1 N_2	N_1 N_2	N_1 N_2
0	0.34	0.19 0.21	0.58 0.60	0.42 0.40
15	0.62	0.45 0.53	0.76 0.82	0.24 0.18
30	0.63	0.46 0.55	0.76 0.83	0.24 0.17
60	0.67	0.50 0.55	0.76 0.83	0.24 0.17
90	0.65	0.45 0.57	0.74 0.82	0.26 0.18
Response	Q**	Q** Q**	Q** Q**	Q** Q**
N				
60	0.56			
100	0.61			
Response	**			
P × N	NS	*	**	**

[z]N_1 = 60 $mg \cdot L^{-1}$; N_2 = 100 $mg \cdot L^{-1}$.
Quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

was applied. At 100 $mg \cdot L^{-1}$ N, SLA increased with all levels of applied P.

For plants sampled 15 DAS, there were no P by N interactions for LAR (Table 3-9). Leaf area ratios increased in quadratic fashion in response to applied P. Most of the P effect occurred between 0 and 15 $mg \cdot L^{-1}$ P. Applied N did not influence LAR values. For plants sampled 22 and 28 DAS, N had no influence on LAR, but LAR was increased with all levels of applied P. With 100 $mg \cdot L^{-1}$ N, the response of LAR to P was greater than with 60 $mg \cdot L^{-1}$ N.

For plants sampled 15 DAS, there were no P by N interactions for LMR and RMR. Both LMR and RMR increased in quadratic fashion in response to applied P. Leaf mass ratio was least, while RMR was greatest with 0 P. Nitrogen at 100 $mg \cdot L^{-1}$ increased LMR, but reduced RMR compared to N at 60 $mg \cdot L^{-1}$. For plants sampled 22 and 28 DAS, LMR values increased in quadratic fashion, while RMR values decreased in a quadratic fashion in response to applied P. Nitrogen had no influence on LMR or RMR, but LMR was increased, while RMR was decreased with all levels of applied P.

Fertigation frequency was every second day in Experiment 3 compared to Experiments 1 and 2 where fertigation frequency ranged from fertigating every two days to fertigating every four days. When fertigation was every two days, fresh and dry root mass increased in response to

15 $mg \cdot L^{-1}$, with no further increases in root mass at higher P concentrations up to 90 $mg \cdot L^{-1}$ even though the initial P concentration in the media was low (0.4 $mg \cdot kg^{-1}$). In Experiment 2, root mass was increased with each level of fertilizer P because the initial P concentration in the media was low (0.6 $mg \cdot kg^{-1}$), indicating that perhaps 60 $mg \cdot L^{-1}$ P was not adequate with the irrigation programs used. Therefore, in a media with less than 0.5 $mg \cdot kg^{-1}$ water extractable P, frequent fertigation is desirable.

These experiments have revealed that P applied via the floatation irrigation system improved growth of both roots and shoots of lettuce transplants, especially when P in the media was low. Melton and Dufault (1991) reported that 5 to 45 $mg \cdot L^{-1}$ P did not influence tomato transplant shoot and root growth. Tremblay et al. (1987) reported that increasing P from 100 to 200 $mg \cdot L^{-1}$ did not influence celery transplant root growth. Their studies did not have a 0 P treatment to compare growth responses with. Lorenz and Vittum (1980) reported that the critical tissue P concentration for most vegetable species is about 3.0 $g \cdot kg^{-1}$ of dry mass. This value corresponded to an application of 15 $mg \cdot L^{-1}$ P in the present work. In all the three experiments conducted, tissue P in plants produced with 0 P was approximately 1.0 $g \cdot kg^{-1}$, while a range of tissue P concentration from 3.0 to 8.6 $g \cdot kg^{-1}$ produced lettuce shoots with similar mass. Based on

these results, a range of 3.0 to 4.0 $g \cdot kg^{-1}$ P can be considered adequate tissue P concentration for production of high quality lettuce transplants. It is not clear, however, why increased N led to more tissue P concentrations. Perhaps bigger plants due to N had greater energy requirements for growth processes and therefore took in more P.

Regardless of season grown, average daily maximum media temperatures were similar, i.e. 31, 33 and 29 °C, while average daily minimum media temperatures were also similar at 22, 26 and 21 °C for Experiments 1, 2, and 3, respectively. Improved shoot growth in Experiment 2 (Sep/Oct) compared to Experiments 1 (Jun/Jul) and 2 (Feb), was probably related to higher temperatures inside the greenhouse during the fall. In Experiment 3, transplants produced with 0 P were very small compared with the previous experiments, probably due to low P (0.4 $mg \cdot kg^{-1}$) in the peat+vermiculite mix as well frequent fertigations, without P, that might have leached any available P in the media. Transplants produced with 0 P in Experiment 3 had similar poor growth, regardless of N concentration. (In Chapters 5 and 6, transplants did not respond to either P or K with 0 N). There was similar shoot and root growth with any level of applied P. Nitrogen at 100 $mg \cdot L^{-1}$ improved shoot growth especially in response to applied P, but additional N adversely affected root growth compared to N at 60 $mg \cdot L^{-1}$.

Results in Chapters 4 and 6 also indicated that applying more than 60 $mg \cdot L^{-1}$ N improved transplant shoot growth, but not root growth.

In general, RGR values were improved, while NAR values were reduced with any level of P. Values of RGR and NAR were larger at 21 than at 28 DAS, indicating that younger plants had greater growth efficiency than older ones. With added P, RSR values were similar in Experiment 1 and 3, but lower in Experiment 2. Higher temperatures in Experiment 2 caused more shoot growth at the expense of root growth. Weston and Zandstra (1989) reported that P from 15 to 60 $mg \cdot L^{-1}$ had no effect on RSR values of tomato transplants. In Chapter 5, lower RSR values were obtained at low temperatures (average daily minimum media temperature of 11 °C), indicating that extreme temperatures adversely affected RSR values. In all the experiments, LMR and RMR were similar regardless of sampling date, implying that there was no shift in dry matter allocation between shoots and roots with time. The same was true for K in Chapter 4, but not for N in Chapters 5 and 6. As N increased, more dry matter became allocated to shoots than to roots, with time.

Results from scanning the roots, revealed that the response of root length and root area paralleled the response of root mass to applied P, regardless of time of transplant production. Quality transplants had total root

lengths were between 276 and 306 cm, and total root area between 26 and 30 cm^2. With any level of applied P, pulling success was improved tremendously compared to 0 P, but pull force was unaffected. Only 30 % of the plants produced with 0 P could be pulled from the transplant flats, compared to approximately 90 % pulling success with added P. In Chapter 6, pull force was related to pulling success, but this was not so in the present work probably because there were smaller differences in root mass among the treatments in the present investigation.

Field Experiments

Plants from Greenhouse Experiment 2 (fall) and Experiment 3 (winter) were grown to maturity to evaluate the effects of pretransplant P on earliness, yield and lettuce head quality.

Plants of all treatments in the fall crop of Experiment 1 were harvested in December, 64 days after transplanting (DAT). Lettuce head mass increased in quadratic fashion in response to pretransplant P (Table 3-10). Head mass was greater from plants receiving P as a pretransplant treatment compared to those plants not receiving P.

Firmness, head height, stem width, and core length increased in a quadratic fashion with pretransplant P. Firmness, and head height ratings were improved by

Table 3-10. Effects of P nutrition during transplant production on lettuce head mass and head quality characteristics for Experiment 1, harvested 20 December 1995.

Phosphorus applied	Head mass	Firm rating[z]	Head height	Head diameter	Stem width	Core length	Leaf tissue P
($mg \cdot L^{-1}$)	(g)	(1-5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)
0	601	4.3	112	120	25	38	2.9
15	743	4.8	124	122	30	54	3.1
30	711	4.9	123	124	31	58	3.0
45	721	4.9	130	129	30	57	2.8
60	738	4.8	127	121	31	63	2.7
Response	Q*	Q**	Q*	NS	Q**	Q*	NS

[z]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

transplant P, while stem width and core length were enlarged. Heads were less developed with 0 P, while heads from transplants produced with 15 to 60 $mg \cdot L^{-1}$ pretransplant P were more developed, indicating greater earliness. At harvest, tissue P levels were equal regardless of pretransplant P because plants were grown in a field with soil high in available P.

Plants of all treatments in the spring crop of Experiment 2 were harvested in May, 64 DAT. There were no P by N interactions for head mass or head quality characteristics. There was a positive linear response of head mass to pretransplant P. Head mass was improved at harvest with all pretransplant P fertilization treatments, but was unaffected by pretransplant N fertilization (Table 3-11).

Stem width increased in quadratic fashion, while core length increased in linear fashion in response to pretransplant P. Stem width and core length were enlarged by transplant P, indicating greater earliness, but were unaffected by pretransplant N. Lettuce head firmness, height, and diameter were unaffected by pretransplant P or N. At harvest, tissue N and P levels were equal regardless of pretransplant P or N applied.

In the field, lettuce head mass was influenced by pretransplant P, regardless of time of production. All

Table 3-11. Effects of P and N nutrition during transplant production on lettuce head mass and head quality characteristics for Experiment 2, harvested 2 May 1996.

Nutrient applied	Head mass	Firm rating[z]	Head height	Head diameter	Stem width	Core length	Leaf tissue N	Leaf tissue P
($mg \cdot L^{-1}$)	(g)	(1-5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)
P								
0	451	4.6	124	103	22	34	36.6	2.1
15	533	4.9	124	107	24	36	35.0	2.0
30	517	4.8	124	104	24	36	34.9	2.1
60	524	4.8	123	108	24	38	36.8	2.1
90	552	4.8	124	108	24	38	34.3	2.2
Response	L**	NS	NS	NS	Q*	L*	NS	NS
N								
60	528	4.8	125	106	24	36	34.7	2.0
100	502	4.7	123	106	23	37	36.3	2.2
Response	NS	NS	NS	NS	NS	NS	NS	NS
P × N	NS	NS	NS	NS	NS	NS	NS	NS

[z]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Linear (L) or quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

pretransplant P treatments had a similar effect of increasing head mass at harvest. Tissue P levels were equal at harvest regardless of pretransplant P applied. Hochmuth et al. (1991) reported values of 25 to 50 $g \cdot kg^{-1}$ P (soil type not reported) to be indicative of an adequate P range for crisphead lettuce. Values of tissue P were slightly less than this in Experiment 2, but plants looked healthy with tissue P of 21 $g \cdot kg^{-1}$. Stem width and core length were improved by pretransplant P, indicating greater earliness due to P fertilization, thus adequate plant size at transplanting. Earliness is of particular significance in north Florida where the growing period is shortened by either low temperatures in fall plantings or high temperatures in spring plantings. Low temperatures could result in lettuce heads freezing, while high temperatures could cause premature bolting. At transplanting, plants produced with pretransplant P were larger than those produced with no P. Therefore, larger plants at transplanting led to earliness and larger head size at harvest.

Summary

'South Bay' lettuce transplants were produced with different levels of P supplied via floatation irrigation, to

determine the optimum P concentration necessary for production of high quality transplants, and subsequent high quality crop in the field. A quality transplant has sufficient roots to fill a tray cell to facilitate ease of pulling from the transplant flat. Plants were propagated by floating flats in a nutrient solution containing either 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ P in summer and fall experiments, and either 0, 15, 30, 60, or 90 $mg \cdot L^{-1}$ P in factorial combination with 60 or 100 mg $N \cdot L^{-1}$ in a winter experiment. Photoperiod was extended to 16 h in all experiments.

Phosphorus applied at frequent rates via the floatation irrigation system affected growth of both roots and shoots of lettuce transplants. However, after the initial P addition of 15 $mg \cdot L^{-1}$, further P additions resulted in a minimal growth response. Transplants produced with 0 P had similar poor growth, regardless of N applied. Nitrogen at 100 $mg \cdot L^{-1}$ improved the response of shoot growth to any level of P, but adversely affected root growth compared to N at 60 $mg \cdot L^{-1}$.

In general, RGR values were improved, while NAR values were reduced with any level of P. Values of RGR and NAR were larger by 21 DAS than by 28 DAS, indicating that younger plants had greater growth efficiency than older ones. Quality transplants had RSR of approximately 0.25, total root lengths between 276 and 306 cm, and total root area

between 26 and 30 cm^2 in a 10.9 cm^3 cell volume. Only 30 % of the plants produced with 0 P could be pulled from the transplant flats, compared to approximately 90 % pulling success with added P. At least 15 $mg \cdot L^{-1}$ P, supplied every two days via floatation irrigation, is recommended for production of high quality lettuce transplants in a peat+vermiculite media containing low concentrations of water extractable P.

All pretransplant P treatments had a similar effect of increasing head mass at harvest time, and in reducing time to maturity regardless of production season. At transplanting, plants produced with transplant P were larger than those produced with no transplant P. Phosphorus fertilization in the transplant cell, led to improved earliness and yields.

This work demonstrated that at least 15 $mg \cdot L^{-1}$ P, supplied via floatation irrigation to a peat+vermiculite mix, was required to build an ideal transplant with sufficient roots to fill a tray cell for ease of pulling out of transplant flats. Phosphorus fertilization also resulted in larger transplants for rapid field establishment, leading to earlier lettuce harvest.

CHAPTER 4

NEED FOR SUPPLEMENTAL POTASSIUM FOR LETTUCE TRANSPLANT PRODUCTION

Introduction

The environmental conditions to which vegetable transplants are exposed during early growth play an important role in final crop yield (Masson et al., 1991b). The early growing environment of transplants can be manipulated in ways that are not possible with direct-seeded crops (Wurr and Fellows, 1982). Several factors that are known to affect vegetable transplant size, quality, and growth in the field include nutritional conditioning before transplanting (Jaworski and Webb, 1966; Jaworski et al., 1967; Kratky and Mishima, 1981; Weston and Zandstra, 1989; Garton and Widders, 1990; Masson et al., 1991a, 1991b; Melton and Dufault, 1991; Dufault and Schultheis, 1994).

The role of fertilizer K in vegetable transplant growth has been investigated. Dufault (1985) produced celery transplants and gave them weekly applications of various N, P, and K solutions. The treatments were factorial

combinations of N at 10, 50, or 250 $mg \cdot L^{-1}$, P at 5, 25, or 125 $mg \cdot L^{-1}$, and K at 10, 50, or 250 $mg \cdot L^{-1}$. Potassium did not affect celery growth. The media contained 40 $mg \cdot L^{-1}$ hydrochloric acid extractable K and may have supplied all the necessary K requirements. Melton and Dufault (1991) grew tomato transplants with either 25, 75, or 225 $mg \cdot L^{-1}$ K applied three times per week. They found that K did not influence transplant height, stem diameter, leaf number, leaf area, total chlorophyll, fresh shoot mass, or dry shoot and root mass. Tomato transplant growth did not respond to fertilizer K probably because the media Melton and Dufault used already contained 103 $mg \cdot L^{-1}$ K (extraction method not reported).

Tremblay and Senécal (1988) grew lettuce, broccoli, pepper, and celery transplants with 150 or 350 $mg \cdot L^{-1}$ N, as well as 50, 200, or 350 $mg \cdot L^{-1}$ K, applied daily. Growth measurements were made at 18, 20, 31, and 38 days after sowing for lettuce, broccoli, pepper, and celery, respectively. They reported that celery and broccoli leaf area increased by adding 50 to 350 $mg \cdot L^{-1}$ K. Leaf area of lettuce was increased with added K only with 350 $mg \cdot L^{-1}$ N, but not with 150 $mg \cdot L^{-1}$ N. Increasing the K concentration in conjunction with 150 $mg \cdot L^{-1}$ N decreased pepper leaf area while, with 350 $mg \cdot L^{-1}$ N, the inverse pattern was true.

Broccoli dry shoot mass increased in response to K, with a maximum at 200 $mg \cdot L^{-1}$ K. Lettuce dry shoot mass was increased more sharply by increasing K when grown with 350 than with 150 $mg \cdot L^{-1}$ N. Celery dry shoot mass was maximized with 200 $mg \cdot L^{-1}$ K when N concentration was 350 $mg \cdot L^{-1}$, but minimum at this K concentration when added N was only 150 $mg \cdot L^{-1}$. The percentage of shoot dry matter in lettuce and pepper increased with K concentration when N was 150 $mg \cdot L^{-1}$, but decreased when N was 350 $mg \cdot L^{-1}$. Root growth characteristics as well as root:shoot ratio for broccoli, celery, and lettuce were not affected by K fertilization.

Most of the previously described experiments were conducted with weekly applications of fertilizer. Data are lacking on the growth response of lettuce roots and shoots to frequent K applications such as practiced in the floatation system of irrigation. In this system, nutrients are supplied with every irrigation by floating flats directly in nutrient solution. Growers using this system have been unable to produce lettuce transplants with sufficient roots in a tray cell to enable easy removal of transplants from the transplant flat (Robles, personal communication). Perhaps optimizing K could improve root development in lettuce transplants.

The present investigation was conducted to determine the optimum K concentration, supplied via floatation

irrigation, that could produce quality transplants with sufficient roots in a tray cell to facilitate easy removal of transplants from the transplant flat, and lead to rapid field establishment. In previous experiments (Chapter 3), photoperiod was extended to 16 h. In order to determine if supplementary light would be of greater benefit in promoting lettuce growth than extended photoperiod during periods of low light intensity, both systems were compared.

Materials and Methods

Greenhouse Experiments

'South Bay' lettuce transplants were grown in a glass greenhouse at the University of Florida, Gainesville, FL. Speedling styrofoam planter flats, model F392A [392 cells of 1.9 × 1.9 × 6.3 cm; 10.9 cm^3 (length × width × depth; volume)], were used for growing plants. A peat+vermiculite+styrofoam bead mix (1:2:1, v/v/v), with AquaGro wetting agent (Aquatrols, Cherry Hill, NJ) at 0.2 $kg \cdot m^{-3}$, was used for media. Three experiments were conducted (Tables 4-1 and 4-2). The plants were grown with natural photoperiod extended to 16 h by 1000-W, high-pressure sodium lamps (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux). A record of cloud cover was kept as an indication of the evaporative demand of the atmosphere. Greenhouse air temperature just

Table 4-1. Sowing schedule and initial media test (Hanlon et al., 1994) for Experiments 1 and 3.

Expt	Sowing date	Media test[z]						
		pH	EC	NO_3-N	P	K	Ca	Mg
			($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)				
1	14 Jul 1993	4.7	0.9	1.3	12.4	14.6	14.2	11.6
3	31 Jan 1996	5.2	0.2	0.3	0.4	24.4	0.6	5.8

[z]Concentrations in the saturated paste extract.

Table 4-2. Initial media test (Hanlon et al., 1994) for Experiment 2, sown 28 January 1994.

Media type	Media test[z]						
	pH	EC	NO_3-N	P	K	Ca	Mg
		($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)				
Peat+vermiculite	4.9	0.1	0	0.7	10.9	0.9	1.8
Peat+rockwool[y]	5.3	0.1	0	0.3	2.5	0.8	0.8
Peat	4.0	0.1	0	0.6	2.0	0.8	1.2

[z]Concentrations in the saturated paste extract.
[y]Forty % hydrofile and 10 % hydrorepellent rockwool.

above the plant canopy, and media temperatures were recorded by a Series 3020T Datalogger (Electronic Controls Design, Inc., Mulino, OR). Separate temperature measurements were made for the treatments under extended photoperiod and those under supplementary light in Experiment 2. Photosynthetically active radiation (PAR) during the plant growing period was measured with a light meter just above the plant canopy. For consistency, measurements were taken at 10:00 h every morning.

The flats were seeded then covered with a thin layer of vermiculite, overhead irrigated enough to moisten the vermiculite, then transferred to a cooler at 20 °C for

germination. After 48 h, flats were returned to the greenhouse.

Plants in Experiment 1 were irrigated every two to four days by floating flats in nutrient solution containing K at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ as KCl. Other nutrients were supplied at equivalent rates to all plants and consisted of (in $mg \cdot L^{-1}$) 100 N, 30 P, 100 Ca, and half-strength Hoagland's solution for micronutrients only (Hoagland and Arnon, 1950) that was comprised of Mg, S, B, Cu, Mo, and Zn. The experiment was a randomized complete-block design with 5 treatments and 4 replications.

Plants in Experiment 2 were grown with either the natural photoperiod extended to 16 h or with supplementary lighting for the entire 16 h photoperiod from 1000-W, high-pressure sodium lamps (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux). Plants were irrigated once every two to four days, by floating flats in nutrient solution containing K at 0 or 60 $mg \cdot L^{-1}$ as KCl. Other nutrients were applied as described for Experiment 1. Peat+vermiculite (1:2, v/v), peat+rockwool (1:1, v/v), and peat media, were used for the experiment. The factorial experiment was arranged in a split-block design. There were 3 replications within each light treatment consisting of 2 levels of K and 3 media.

Plants in Experiment 3 were irrigated every other day by floating flats in nutrient solution containing K at 0,

15, 30, 45, or 60 $mg \cdot L^{-1}$ in combination with N at 60 or 100 $mg \cdot L^{-1}$. Potassium was supplied from KCl, while N was supplied from NH_4NO_3. Other nutrients were applied as described for Experiment 1. The experiment was a randomized complete-block design with 10 treatments consisting of a factorial combination of 5 levels of K and 2 levels of N, replicated four times.

Plant samples, 5 per treatment, were taken at approximately 14, 21, and 28 days after sowing (DAS) for growth measurements. Measurements included shoot and root fresh and dry mass, and leaf area (measured by a LI-3100 leaf area meter; LI-COR, Lincoln, NE). Growth variables calculated were: root:shoot ratio (RSR = dry root mass ÷ dry shoot mass), relative growth rate (RGR = [ln (final total dry mass) - ln (initial total dry mass) ÷ (final time - initial time)]), net assimilation rate (NAR = [(final total dry mass - initial total dry mass) ÷ (final time - initial time) × {(ln (final leaf area) - ln (initial leaf area)} ÷ (final leaf area - initial leaf area)]), specific leaf area (SLA = leaf area ÷ dry shoot mass), leaf area ratio (LAR = leaf area ÷ total dry mass), leaf mass ratio (LMR = dry shoot mass ÷ total dry mass), and root mass ratio (RMR = dry root mass ÷ total dry mass) (Hunt, 1978; 1982; Dubik et al., 1992).

Leaf petioles were collected at 23 and 30 DAS in Experiment 2, and at the last sampling dates in Experiments 1 and 3 for sap testing. The sap was squeezed from collected petiole pieces using a hydraulic sap press onto sampling sheets according to Hochmuth (1992). A CARDY meter (Spectrum Technologies, Inc., Plainfield, IL) was used to measure K^+ concentrations in the petiole sap.

Dry shoot samples from the last sampling dates were ground to pass a 20-mesh screen and dry-ashed for K or acid-digested for total Kjeldahl N according to Wolf (1982). For total K determination, 0.5 g subsamples were weighed into 10 mL beakers. The samples were then dry-ashed in a muffle furnance at 500 °C for 10 h. The ash was moistened with 1 N HCl and poured into 50 mL volumetric flasks, and brought to volume with 1 N HCl. The solutions were filtered through 'Q8' filter papers (Fisher brand), with a particle retention of > 10 μm, into 25 mL scintillation vials. The solution samples were sent to the Analytical Research Laboratory, University of Florida, and analyzed with Model 61-E Inductively Coupled Plasma Spectrometry (Thermo Jarrell Ash Corporation, Franklin, MA).

The acid digestion procedure consisted of weighing 0.25 g subsamples into 50 mL digestion tubes. Sulfuric acid and 30 % hydrogen peroxide were added to the tubes, which were then heated on a digestion block at 375 °C. After the

digestion process was completed (a total of 2.5 h), the samples were allowed to cool, and deionized water was used to bring the volume to 25 mL. The solutions were filtered through 'P8' filter papers (Fisher brand), with a particle retention of > 25 μm, into 25 mL scintillation vials. The solution samples were sent to the Analytical Research Laboratory, University of Florida, and N was determined on a 300 Series Rapid Flow Analyzer (ALPKEM Corporation, Wilsonville, OR).

Data were subjected to analysis of variance using PROC GLM and/or PROC MIXED (SAS Institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear or quadratic polynomial contrasts in Experiments 1 and 3. Plants in the peat mix in Experiment 2 did not grow, perhaps due to poor aeration, therefore the treatment was eliminated from data analysis.

Field Experiment

Plants from each treatment in Greenhouse Experiment 3 were transplanted into an Arredondo fine sandy soil (loamy, siliceous, hyperthermic Grosarenic Paleudults) in beds covered with white-on black polyethylene-mulch (0.038 mm thick) at the University of Florida Horticultural Unit, Gainesville, on 29 February 1996. The soil had a water pH of 5.8, with 0 $dS \cdot m^{-1}$ for electrical conductivity, and a

nutrient content (Hanlon et al., 1994) of (in $mg \cdot kg^{-1}$) 247 P, 37 K, 695 Ca, and 43 Mg (Mehlich-1 extractant). The experiment was a randomized complete-block design with 10 treatments consisting of a factorial combination of 5 levels of K and 2 levels of N, with each treatment replicated four times. Preplant fertilizer (13N-0P-10.8K) was applied broadcast and incorporated in the bed at 230 $kg \cdot ha^{-1}$. Raised beds spaced 1.2 m center to center, were fumigated with methyl bromide and then covered with the polyethylene mulch. There were 30 plants per plot planted on double offset rows with a spacing of 0.3 m between plants and between rows on the bed, equivalent to 54,000 plants/ha.

Just after transplanting, 100 mL of nutrient solution (150 $mg \cdot L^{-1}$ 20N-8.6P-16.7K) was applied to each transplant hole as a starter fertilizer. Water was applied daily for 45 min each cycle, using drip irrigation lines placed on the center of the bed with emitters spaced 0.3 m apart. Tensiometers (Irrometer Company, Inc., Riverside, CA) were used to monitor soil moisture adequacy in the beds. The root zone area was maintained at approximately -10 kPa according to Hochmuth and Clark (1991). Starting one week after transplanting, fertilizer at a rate of 15 $kg \cdot ha^{-1}$ N and 16 $kg \cdot ha^{-1}$ K as NH_4NO_3 and KNO_3, was injected once weekly using a venturi pump (Netafim Irrigation, Altamonte Springs, FL), with the last application one week before harvest to give a

total amount of 150 $kg \cdot ha^{-1}$ N and 180 $kg \cdot ha^{-1}$ K. Cultural management practices were similar to those used commercially in Florida (Hochmuth et al., 1988).

At lettuce head maturity, the center 20 plants in a plot were cut, individually weighed, and then 10 heads were assessed for firmness, cut longitudinally for height, diameter, stem width, and core length measurements. Wrapper leaves were sampled at harvest for analysis of tissue K and N according to Wolf (1982) as described for Greenhouse Experiments. Field data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

Results and Discussion

Greenhouse Experiments

Experiment 1 was conducted during the summer under greenhouse temperatures ranging from 22 to 36 °C (Fig. 4-1). The average daily maximum media temperature was 32 °C, while the average daily minimum media temperature was 23 °C. During the course of the experiment, there were totals of 25 sunny days of which two were followed with rain in the afternoon, and 2 cloudy days.

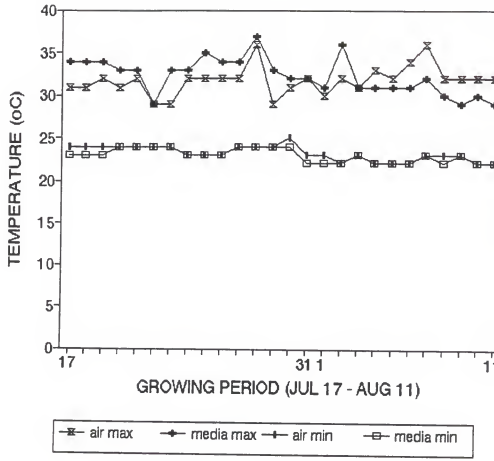


Fig. 4-1. Maximum and minimum air and media temperature during transplant production for Experiment 1, Jul/Aug 1993.

For plants sampled 15, 21, and 28 days after sowing (DAS), applied K did not influence fresh and dry shoot mass (Table 4-3). For plants sampled 15 and 21 DAS, applied K did not influence fresh and dry root mass. However, by 28 DAS, there was a positive linear response of fresh and dry root mass to applied K. For plants sampled 15 DAS, leaf area increased linearly to applied K, but by later sampling dates, applied K did not influence leaf area.

For plants grown to 21 or 28 DAS, there was a positive linear increase in petiole sap K in response to applied K. Leaf tissue K also increased linearly to applied K. Therefore, increased root growth was associated with increased tissue K.

For plants sampled 15, 21, and 28 DAS, RSR values were not influenced by applied K, since shoots were unaffected while there was little increase in root growth due to added K (Table 4-4). For plants grown to 21 DAS, RGR, and NAR values responded in quadratic fashion in response to applied K. Relative growth rates and NAR values were least with 30 $mg \cdot L^{-1}$ K and greatest with 60 $mg \cdot L^{-1}$ K. By 28 DAS, RGR and NAR were not influenced by K. For plants sampled 15 DAS, SLA and LAR increased linearly in response to applied K. For plants sampled 21 and 28 DAS, SLA, and LAR were not influenced by K.

Table 4-3. Root and shoot characteristics of lettuce transplants as affected by K nutrition for Experiment 1, July/August 1993.

Potassium applied	Fresh shoot mass	Dry shoot mass	Fresh root mass	Dry root mass	Leaf area	Leaf petiole sap K	Leaf tissue K
($mg \cdot L^{-1}$)	(mg)	(mg)	(mg)	(mg)	(cm^2)	($mg \cdot L^{-1}$)	($g \cdot kg^{-1}$)
			15 Days After Sowing				
0	152	9.7	56	3.6	6.4		
15	177	10.5	57	3.9	7.2		
30	183	11.2	57	3.8	7.7		
45	172	10.5	54	3.6	7.4		
60	175	10.2	50	3.5	7.4		
Response	NS	NS	NS	NS	L*		
			21 Days After Sowing				
0	704	40.2	167	10.4	26.4	2725	
15	699	41.1	182	11.3	26.3	2800	
30	721	39.4	183	10.8	27.1	2900	
45	734	40.2	182	11.1	28.1	2950	
60	726	41.2	214	13.0	26.8	3075	
Response	NS	NS	NS	NS	NS	L**	
			28 Days After Sowing				
0	1366	80.0	298	19.9	46.3	2300	41.9
15	1347	82.4	296	20.8	46.5	2125	42.8
30	1395	80.7	302	20.8	47.6	2325	47.6
45	1454	88.3	324	22.4	49.6	2825	48.0
60	1474	85.6	333	22.8	50.2	2450	48.7
Response	NS	NS	L*	L**	NS	L**	L**

Linear (L) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

Table 4-4. Influence of K nutrition on growth characteristics of lettuce transplants, Experiment 1, July/August 1993.

Potassium applied ($mg \cdot L^{-1}$)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			15 Days After Sowing				
0	0.37			0.66	0.48	0.73	0.27
15	0.38			0.69	0.50	0.73	0.27
30	0.34			0.68	0.51	0.75	0.25
45	0.34			0.70	0.52	0.75	0.25
60	0.34			0.73	0.54	0.75	0.25
Response	NS			L*	L**	NS	NS
			21 Days After Sowing				
0	0.26	1.33	2.66	0.66	0.52	0.79	0.21
15	0.28	1.30	2.59	0.64	0.50	0.78	0.22
30	0.28	1.21	2.30	0.69	0.54	0.78	0.22
45	0.32	1.29	2.40	0.70	0.55	0.78	0.22
60	0.32	1.38	2.70	0.65	0.49	0.76	0.24
Response	NS	Q**	Q*	NS	NS	NS	NS
			28 Days After Sowing				
0	0.25	0.68	1.40	0.58	0.46	0.80	0.20
15	0.25	0.68	1.43	0.56	0.45	0.80	0.20
30	0.26	0.70	1.41	0.59	0.47	0.80	0.20
45	0.25	0.77	1.57	0.56	0.45	0.80	0.20
60	0.27	0.69	1.45	0.59	0.46	0.79	0.21
Response	NS	NS	NS	NS	NS	NS	NS

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

Applied K did not influence LMR or RMR values, regardless of sampling date (Table 4-4). For plants sampled 15 DAS, approximately 75 % of the lettuce transplant dry matter was allocated to shoots and 25 % allocated to roots. As the plants grew older, by 28 DAS, proportionally more dry matter became allocated to shoots (80 %) compared to roots (20 %).

Results of Experiment 1 indicated that K applied to a peat+vermiculite media with 15 $mg \cdot L^{-1}$ water extractable K, increased transplant root growth, but not shoot growth. Sufficient K for shoot growth may have been available or released from the media during the growing cycle.

In Experiment 2, transplant growth response to K was compared among three media types, peat, peat+rockwool, and peat+vermiculite mixes. Peat and rockwool (molten, spun basalt rock fibers) have inherently lower K levels than vermiculite (Table 4-2). Since the experiment was conducted in February when light intensities are normally low, the benefit of supplementary light for 16 h was compared with an extension of the photoperiod to 16 h.

Experiment 2 was conducted during the winter, under greenhouse temperatures ranging from 8 to 37 °C (Figs 4-2 and 4-3). The average daily maximum media temperatures were 24 and 26 °C under extended photoperiod and under supplementary light, respectively. Average daily minimum

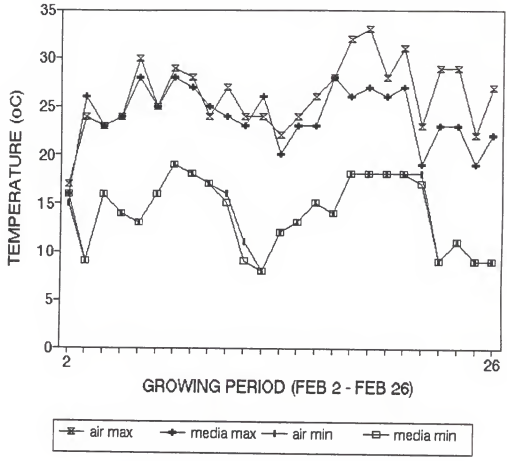


Fig. 4-2. Maximum and minimum air and media temperature during transplant production under extended photoperiod for Experiment 2, February 1994.

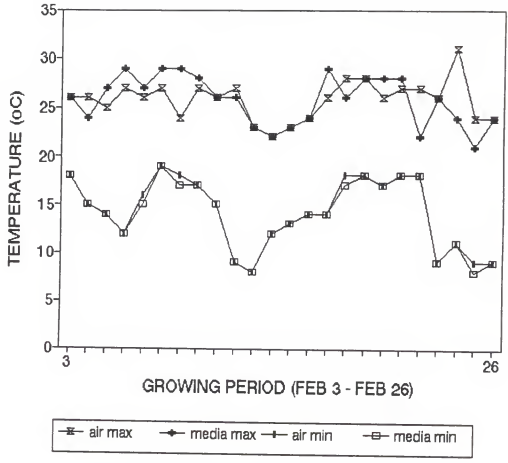


Fig. 4-3. Maximum and minimum air and media temperature during transplant production under supplementary lighting for Experiment 2, February 1994.

media temperature was 14 °C with both light treatments. During the course of the experiment, there were totals of 13 sunny and 16 cloudy days. Supplementary light contributed more than natural light to the light integral (PAR) received in the greenhouse by the lettuce transplants (Fig. 4-4).

For plants sampled 23 DAS, light, K, and media did not interact to influence fresh shoot mass (Table 4-5). Light and media treatments did not influence fresh shoot mass, while more fresh shoot mass occurred in transplants grown with 60 $mg \cdot L^{-1}$ than with no K. Supplementary light for 16 h led to increased dry shoot mass compared to extending the photoperiod to 16 h, particularly in peat+vermiculite compared to peat+rockwool mix.

For plants sampled 30 DAS, both K and media influenced fresh and dry shoot mass (Table 4-6). When produced with 60 $mg \cdot L^{-1}$ K, plants grown in peat+rockwool mix had more fresh shoot mass than plants grown in the peat+vermiculite mix. There was no response in dry shoot mass to applied K in the peat+vermiculite mix. In peat+rockwool mix, applied K resulted in an increase in dry shoot mass. Plants grown with supplementary light for 16 h had greater shoot mass than those grown with the photoperiod extended to 16 h.

For plants sampled 23 DAS, only the media used influenced fresh root mass; there was no effect of added K or light (Table 4-5). Root mass of plants grown in

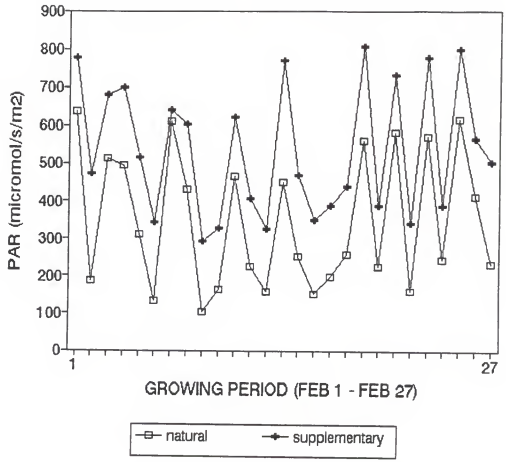


Fig. 4-4. Photosynthetically active radiation (PAR) under natural or supplementary lighting for Experiment 2, February 1994.

Table 4-5. Root and shoot characteristics of lettuce transplants 23 days after sowing as affected by light, potassium, and media for Experiment 2, February 1994.

Mix	Light[z] (h)			K ($mg \cdot L^{-1}$)		
	4	16	*Response*	0	60	*Response*
			Fresh shoot mass (mg)			
Peat+vermiculite	1003	1014	NS	1005	1012	NS
Peat+rockwool	1096	1057	NS	999	1154	**
Response	NS	NS		NS	*	
			Dry shoot mass (mg)			
Peat+vermiculite	61.4	83.6	**	72.8	72.2	NS
Peat+rockwool	59.0	69.6	*	54.7	73.9	**
Response	NS	**		**	NS	
			Fresh root mass (mg)			
Peat+vermiculite	222	294	*	257	260	NS
Peat+rockwool	195	229	NS	199	226	NS
Response	NS	**		**	*	
			Dry root mass (mg)			
Peat+vermiculite	11.1	16.8	NS	14.1	13.8	NS
Peat+rockwool	9.4	15.3	NS	11.9	12.8	NS
Response	NS	NS		NS	NS	
			Leaf area (cm^2)			
Peat+vermiculite	36.7	35.8	NS	36.9	35.6	NS
Peat+rockwool	36.9	35.6	NS	31.1	41.4	**
Response	NS	NS		**	**	
			Leaf petiole sap K ($mg \cdot L^{-1}$)			
Peat+vermiculite	2183	1967	NS	1950	2200	*
Peat+rockwool	588	498	NS	101	985	**
Response	**	**		**	**	
			Root:shoot ratio			
Peat+vermiculite	0.18	0.20	NS	0.19	0.19	NS
Peat+rockwool	0.16	0.23	NS	0.22	0.17	NS
Response	NS	NS		NS	NS	
			Specific leaf area ($cm^2 \cdot mg^{-1}$)			
Peat+vermiculite	0.60	0.43	**	0.52	0.51	NS
Peat+rockwool	0.62	0.52	*	0.57	0.57	NS
Response	NS	**		**	**	
			Leaf area ratio ($cm^2 \cdot mg^{-1}$)			
Peat+vermiculite	0.51	0.36	**	0.44	0.43	NS
Peat+rockwool	0.54	0.42	*	0.47	0.49	NS
Response	NS	**		NS	**	
			Leaf mass ratio			
Peat+vermiculite	0.85	0.84	NS	0.84	0.84	NS
Peat+rockwool	0.86	0.82	NS	0.82	0.86	NS
Response	NS	NS		NS	NS	
			Root mass ratio			
Peat+vermiculite	0.15	0.16	NS	0.16	0.16	NS
Peat+rockwool	0.14	0.18	NS	0.18	0.14	NS
Response	NS	NS		NS	NS	

[z]Natural photoperiod extended by 4 h to 16 h or supplementary light for the entire 16 h.

NS, *, **Nonsignificant (NS) or significant t-test at 5% (*), 1% (**) levels.

Table 4-6. Root and shoot characteristics of lettuce transplants 30 days after sowing as affected by light, potassium, and media for Experiment 2, February 1994.

Mix	Light[z] (h)			K ($mg \cdot L^{-1}$)		
	4	16	*Response*	0	60	*Response*
			Fresh shoot mass (mg)			
Peat+vermiculite	1450	1427	NS	1456	1422	NS
Peat+rockwool	1575	1598	NS	1329	1844	**
Response	NS	*		NS	**	
			Dry shoot mass (mg)			
Peat+vermiculite	110.6	134.3	*	123.9	121.0	NS
Peat+rockwool	103.7	131.4	*	93.1	142.0	**
Response	NS	NS		**	**	
			Fresh root mass (mg)			
Peat+vermiculite	348	450	*	378	420	*
Peat+rockwool	289	327	NS	238	377	**
Response	**	**		**	*	
			Dry root mass (mg)			
Peat+vermiculite	26.8	36.6	**	29.8	33.6	**
Peat+rockwool	20.8	25.9	*	17.7	28.9	**
Response	**	**		**	**	
			Leaf area (cm^2)			
Peat+vermiculite	52.3	50.1	NS	52.0	50.4	NS
Peat+rockwool	52.6	50.7	NS	38.5	64.8	**
Response	NS	NS		**	**	
			Leaf petiole sap K ($mg \cdot L^{-1}$)			
Peat+vermiculite	2467	2083	**	1917	2633	**
Peat+rockwool	593	585	NS	78	1100	**
Response	**	**		**	**	
			Leaf tissue K ($g \cdot kg^{-1}$)			
Peat+vermiculite	37.8	30.1	*	30.3	37.7	**
Peat+rockwool	11.0	9.0	NS	2.7	17.3	**
Response	**	**		**	**	

[z]Natural photoperiod extended by 4 h to 16 h or supplementary light for the entire 16 h.

NS, *, **Nonsignificant (NS) or significant t-test at 5% (*), 1% (**) levels.

peat+vermiculite mix was greater than for plants grown in peat+rockwool mix. Dry root mass of plants sampled 23 DAS was not affected by any treatment. By 30 DAS, plants grown in peat+vermiculite mix had greater fresh and dry root mass compared to those in peat+rockwool mix under both light treatments (Table 4-6). Fresh root mass was increased by supplementary light only when peat+vermiculite mix was used. For both media types, fresh and dry root mass were greater with 60 $mg \cdot L^{-1}$ K compared to no K. The greatest dry root mass was 36.6 mg obtained from plants grown in peat+vermiculite mix with supplementary light. The greatest dry root mass from the peat+rockwool mix was 28.9 mg, obtained from plants grown with 60 $mg \cdot L^{-1}$ K.

Regardless of sampling date, applied K did not influence leaf area when plants were grown in peat+vermiculite mix, indicating sufficient K in the media (Tables 4-5 and 4-6). The plants had greater leaf area when 60 $mg \cdot L^{-1}$ K compared to no K was added to peat+rockwool mix. With no K, plants in peat+vermiculite mix had greater leaf area than plants in peat+rockwool mix. The opposite was true with 60 $mg \cdot L^{-1}$ K.

For plants grown to 23 DAS (Table 4-5), petiole sap K concentration was greater when plants were grown in peat+vermiculite mix instead of peat+rockwool mix. Petiole sap K increased when K was applied to either media type. By

30 DAS (Table 4-6), plants grown with 60 $mg \cdot L^{-1}$ K had more petiole sap K than those grown with no K. Plants grown in peat+vermiculite mix had greater concentrations of petiole sap K than those grown in peat+rockwool mix. It is not clear why in peat+vermiculite mix, supplementary light resulted in lower petiole sap K, while petiole sap K values were not influenced by light treatment for plants grown in peat+rockwool mix.

Plants grown in peat+vermiculite mix had greater total leaf tissue K concentration than plants grown in peat+rockwool mix due to inherently higher levels of K in vermiculite (Table 4-6). It is unclear why supplementary light, compared with an extension of the photoperiod, resulted in lower leaf K concentration in plants grown in peat+vermiculite mix but not in peat+rockwool mix. Plants grown with 60 $mg \cdot L^{-1}$ K had greater K concentration in the leaves compared to plants grown with no K, especially those plants grown in peat+rockwool mix.

For plants sampled 23 DAS, neither of the treatments influenced RSR values (Table 4-5). For plants sampled 30 DAS, RSR was affected by both K and media (Table 4-7). Plants grown with 60 $mg \cdot L^{-1}$ K in peat+vermiculite mix had greater RSR values than those grown with no K, because added K increased dry root mass but not dry shoot mass. Plants grown in peat+vermiculite mix also had greater RSRs than

Table 4-7. Influence of light, potassium, and media on growth characteristics of lettuce transplants 30 days after sowing for Experiment 2, February 1994.

Mix	Light[z] (h)			K ($mg \cdot L^{-1}$)		
	4	16	*Response*	0	60	*Response*
			Root:shoot ratio			
Peat+vermiculite	0.25	0.27	NS	0.24	0.28	**
Peat+rockwool	0.20	0.20	NS	0.19	0.20	NS
Response	**	**		**	**	
			Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)			
Peat+vermiculite	0.64	0.54	NS	0.58	0.60	NS
Peat+rockwool	0.59	0.60	NS	0.50	0.68	**
Response	NS	NS		NS	NS	
			Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)			
Peat+vermiculite	1.48	1.68	NS	1.53	1.63	NS
Peat+rockwool	1.24	1.66	NS	1.29	1.61	NS
Response	NS	NS		NS	NS	
			Specific leaf area ($cm^2 \cdot mg^{-1}$)			
Peat+vermiculite	0.48	0.37	*	0.42	0.43	NS
Peat+rockwool	0.50	0.38	**	0.42	0.46	NS
Response	NS	NS		NS	NS	
			Leaf area ratio ($cm^2 \cdot mg^{-1}$)			
Peat+vermiculite	0.38	0.29	*	0.34	0.33	NS
Peat+rockwool	0.42	0.32	**	0.36	0.39	NS
Response	NS	NS		NS	*	
			Leaf mass ratio			
Peat+vermiculite	0.80	0.79	NS	0.81	0.78	*
Peat+rockwool	0.83	0.84	NS	0.84	0.83	NS
Response	**	**		**	**	
			Root mass ratio			
Peat+vermiculite	0.20	0.21	NS	0.19	0.22	*
Peat+rockwool	0.17	0.16	NS	0.16	0.17	NS
Response	**	**		**	**	

[z]Natural photoperiod extended by 4 h to 16 h or supplementary light for the entire 16 h.

NS, *, **Nonsignificant (NS) or significant t-test at 5% (*), 1% (**) levels.

plants grown in peat+rockwool mix. Added K did not influence RSRs for plants grown in peat+rockwool mix. For plants grown to 30 DAS (Table 4-7), RGR values were lower in peat+rockwool mix with no K than with 60 $mg \cdot L^{-1}$ K, while in the peat+vermiculite mix, RGR was not affected by K. Neither treatment influenced NAR. In Experiment 1, RGR and NAR were also not influenced by added K in a peat+vermiculite mix.

When photoperiod was extended to 16 h, plants grown with no K in either mix had similar SLA values by 23 DAS, but when grown with 60 $mg \cdot L^{-1}$ K, those plants grown in peat+rockwool mix had greater SLA values than plants in peat+vermiculite mix (Table 4-8). Application of 60 $mg \cdot L^{-1}$ K led to smaller SLA values compared to no K when plants were grown in peat+vermiculite compared to peat+rockwool mix. Under 16 h supplementary light, SLA values were not influenced by applied K in either media. With no K, SLA values were greater in peat+rockwool than in peat+vermiculite mix. For plants sampled 23 DAS (Table 4-5), 16 h supplementary light reduced SLA compared to extended photoperiod, particularly when plants were grown in peat+vermiculite than in peat+rockwool mix.

For plants sampled 30 DAS, supplementary light for 16 h led to decreased SLA and LAR compared to simply extending the photoperiod to 16 h (Table 4-7). A low SLA is desirable, though, because it is associated with a thicker leaf.

Table 4-8. Influence of light, potassium, and media on SLA of lettuce transplants 23 days after sowing for Experiment 2, February 1994.

Mix	Light[z] (h)					
	4			16		
	K ($mg \cdot L^{-1}$)			K ($mg \cdot L^{-1}$)		
	0	60	*Response*	0	60	*Response*
	Specific leaf area ($cm^2 \cdot mg^{-1}$)					
Peat+vermiculite	0.63	0.57 **		0.42	0.44 NS	
Peat+rockwool	0.61	0.64 NS		0.53	0.50 NS	
Response	NS	**		**	NS	

[z]Natural photoperiod extended by 4 h to 16 h or supplementary light for the entire 16 h.

NS, *, **Nonsignificant (NS) or significant t-test at 5% (*), 1% (**) levels.

According to Masson et al. (1991a), under high photosynthetic photon flux density, the palisade layer cells generally elongate so that the leaves are thicker, resulting in a decrease in SLA. Greater leaf area ratios for plants grown in peat+rockwool than in peat+vermiculite was associated with greater leaf areas in comparison to dry shoot mass in these plants.

Neither treatment affected LMR or RMR values for plants sampled 23 DAS (Table 4-5). By 30 DAS, plants grown with 60 $mg \cdot L^{-1}$ K had smaller LMR values compared with plants grown without K. Similarly, plants grown in peat+vermiculite mix had smaller LMR values than plants grown in peat+rockwool mix. The opposite response to applied K and to media type occurred for RMR. Once again, added K increased root growth more than shoot growth.

In Experiment 2, plants grown in peat+rockwool mix (3 $mg \cdot kg^{-1}$ water extractable K) responded more to applied K compared with plants grown in peat+vermiculite mix (11 $mg \cdot kg^{-1}$ water extractable K) because, unlike vermiculite, rockwool is inherently low in K. In the peat+rockwool mix, 60 $mg \cdot L^{-1}$ K compared to no K led to increases in shoot, root, and leaf growth. Potassium fertilization also led to increased K concentrations in transplant leaves. Root mass responded more to K and media treatments at 30 than at 23

DAS, indicating that treatment effects on root growth became more apparent with time.

In general, RSR, RGR, NAR, SLA, and LAR were not affected by K. Even though these transplant growth characteristics were not affected by K, transplants grown with no K in the peat+rockwool mix had inferior quality since they could not be easily removed from the transplant flat (data not provided). Stems broke during removal in plants grown with no K, rather than breaking at the root-shoot interface as with plants without N (Chapters 5 and 6) or P (Chapter 3).

In the previous two experiments, 100 $mg \cdot L^{-1}$ N was used when growing transplants at various levels of K. Subsequent studies with N in Chapter 6, however, revealed that optimum N for lettuce transplant root growth might be in the 60 $mg \cdot L^{-1}$ range or less, supplied every second day through floatation irrigation. Therefore, in Experiment 3, N was included as a variable to compare 60 versus 100 $mg \cdot L^{-1}$ N concentration at selected levels of K.

In order to further test the conclusion reached in Experiment 1 that supplemental K may not be necessary for production of high quality transplants in a peat+vermiculite mix, Experiment 3 was conducted during the winter, instead of summer, under greenhouse temperatures ranging from 14 to 38 °C (Fig. 4-5). The average daily maximum media

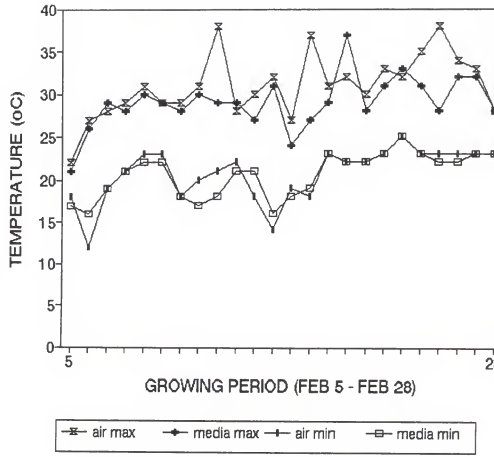


Fig. 4-5. Maximum and minimum air and media temperature during transplant production for Experiment 3, February 1996.

temperature was 29 °C, while the average daily minimum media temperature was 21 °C. During the course of the trial, there were totals of 17 sunny and 9 cloudy days.

For plants sampled 15, 22, or 28 DAS, there were no K by N interactions for dry shoot mass (Table 4-9). For plants sampled 15 and 28 DAS, dry shoot mass was unaffected by K. For plants sampled 22 DAS, there was a negative linear response of dry shoot mass was to applied K. Plants grown with 100 $mg \cdot L^{-1}$ N had greater shoot mass than those grown with 60 mg $N \cdot L^{-1}$, regardless of sampling date.

For plants sampled 15, 22, or 28 DAS, there were no K by N interactions for dry root mass. Potassium did not influence dry root mass, regardless of sampling date. Nitrogen did not influence root mass of plants sampled 15 DAS, but by 22 and 28 DAS, plants grown with 60 $mg \cdot L^{-1}$ N had greater root mass than plants grown with 100 $mg \cdot L^{-1}$ N.

There were no K by N interactions for leaf area of plants sampled 15 and 22 DAS. Potassium did not influence leaf area of plants at these sampling dates. There was greater leaf area for plants grown with 100 than with 60 $mg \cdot L^{-1}$ N. For plants sampled 28 DAS, N at 60 $mg \cdot L^{-1}$ led to a decrease in leaf area when K was applied, while at the 100 $mg \cdot L^{-1}$ level, applied K did not influence leaf area. Tremblay and Senécal (1988) reported that leaf area of

Table 4-9. Root and shoot characteristics of lettuce transplants as affected by K and N nutrition for Experiment 3, February 1996.

Nutrient applied ($mg \cdot L^{-1}$)	Dry shoot mass (mg)	Dry root mass (mg)	Leaf area (cm^2)		Leaf tissue N ($g \cdot kg^{-1}$)	Leaf tissue K ($g \cdot kg^{-1}$)	Root: shoot ratio
			15 Days After Sowing				
K							
0	9.6	3.0	7.3				0.31
15	9.5	3.2	7.2				0.34
30	9.3	3.0	7.3				0.33
45	9.0	2.8	7.0				0.32
60	9.2	3.1	7.1				0.34
Response	NS	NS	NS				NS
N							
60	8.9	3.0	6.8				0.34
100	9.7	3.0	7.5				0.31
Response	**	NS	**				**
K × N	NS	NS	NS				NS
			22 Days After Sowing				
K							
0	45.4	11.7	31.2				0.26
15	45.5	11.7	30.8				0.26
30	45.9	12.7	30.0				0.28
45	42.6	11.9	30.5				0.29
60	42.1	12.7	31.8				0.31
Response	L**	NS	NS				L**
N							
60	40.0	13.4	26.3				0.34
100	48.6	10.9	35.4				0.23
Response	**	**	**				**
K × N	NS	NS	NS				NS
			28 Days After Sowing				
			N_1	N_2			
K							
0	93.9	25.1	51.4	67.2	23.5	36.5	0.27
15	91.5	24.9	47.8	71.6	23.6	38.8	0.28
30	95.7	25.4	51.5	73.5	23.3	45.1	0.27
45	91.2	23.9	45.8	74.4	22.5	49.6	0.27
60	88.6	24.8	45.6	72.1	22.4	53.2	0.29
Response	NS	NS	L**	NS	L**	L**	NS
N							
60	80.1	26.7			18.8	45.5	0.33
100	104.3	23.0			27.4	43.8	0.22
Response	**	**			**	NS	**
K × N	NS	NS	*		NS	NS	NS

[z] N_1 = 60 $mg \cdot L^{-1}$; N_2 = 100 $mg \cdot L^{-1}$.

Linear (L).

NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

lettuce transplants increased in response to applied K from 50 to 350 $mg \cdot L^{-1}$ with 350 $mg \cdot L^{-1}$ N, but not with 150 $mg \cdot L^{-1}$ N.

There were no K by N interactions for leaf tissue N or leaf tissue K (Table 4-9). There was a negative linear response of leaf tissue N to applied K. Leaf tissue K increased in a linear fashion to applied K, but this increase did not influence shoot or root growth. Plants had similar K concentrations in the leaves, regardless of applied N. Nitrogen concentrations were greater in leaves of plants grown with 100 than with 60 $mg \cdot L^{-1}$ N.

For plants sampled 15, 22, or 28 DAS, there were no K by N interactions for RSR. For plants sampled 15 and 28 DAS, applied K did not influence RSR values. For plants sampled 22 DAS, RSR values increased in linear fashion in response to applied K, since there was a concomitant decrease in dry shoot mass by this sampling date. Root:shoot ratios were greater in plants grown with 60 than 100 $mg \cdot L^{-1}$ N, regardless of sampling date.

There were no K by N interactions for RGR or NAR, regardles of sampling date (Table 4-10). For plants grown to 22 and 28 DAS, applied K did not influence RGR values. However, RGR values were greater with 100 than 60 $mg \cdot L^{-1}$ N by both sampling dates. For plants grown to 22 DAS, NAR responded in quadratic fashion to applied K. Net assimilation rate was greatest with 30 $mg \cdot L^{-1}$ K and least

Table 4-10. Influence of K and N nutrition on growth characteristics of lettuce transplants for Experiment 3, February 1996.

Nutrient applied ($mg \cdot L^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)		Leaf mass ratio	Root mass ratio
		15 Days After Sowing					
K				N_1	N_2		
0			0.77	0.60	0.57	0.76	0.24
15			0.76	0.56	0.57	0.75	0.25
30			0.79	0.58	0.61	0.75	0.25
45			0.77	0.57	0.60	0.76	0.24
60			0.78	0.55	0.61	0.74	0.26
Response			NS	NS	L**	NS	NS
N							
60			0.77			0.75	0.25
100			0.78			0.76	0.24
Response			NS			**	**
K × N			NS	*		NS	NS
		22 Days After Sowing					
K							
0	1.52	2.71	0.69	0.55		0.79	0.21
15	1.50	2.75	0.68	0.54		0.79	0.21
30	1.57	2.93	0.66	0.51		0.78	0.22
45	1.53	2.71	0.71	0.55		0.78	0.22
60	1.50	2.60	0.75	0.58		0.76	0.24
Response	NS	Q*	Q*	NS		L**	L**
N							
60	1.50	2.87	0.66	0.49		0.75	0.25
100	1.55	2.61	0.73	0.60		0.82	0.18
Response	**	**	**	**		**	**
K × N	NS	NS	NS	NS		NS	NS
		28 Days After Sowing					
K		N_1	N_2	N_1	N_2		
0	0.74	1.43	0.61	0.65	0.47	0.53	0.79	0.21
15	0.71	1.36	0.62	0.68	0.46	0.55	0.78	0.22
30	0.73	1.43	0.61	0.69	0.46	0.57	0.79	0.21
45	0.75	1.42	0.60	0.71	0.45	0.58	0.79	0.21
60	0.73	1.37	0.59	0.72	0.44	0.59	0.78	0.22
Response	NS	NS	NS	L**	NS	L**	NS	NS
N								
60	0.70	1.48					0.75	0.25
100	0.76	1.32					0.82	0.18
Response	*	**					**	**
K × N	NS	NS	*		**		NS	NS

[z] N_1 = 60 $mg \cdot L^{-1}$; N_2 = 100 $mg \cdot L^{-1}$.

Linear (L) or quadratic (Q).

NS, *, **Nonsignificant (S) or significant at 5% (*), 1% (**) levels.

with 60 $mg \cdot L^{-1}$ K. Potassium did not influence NAR by 28 DAS. Net assimilation rate was greater for plants grown with 60 $mg \cdot L^{-1}$ N, compared to plants receiving 100 $mg \cdot L^{-1}$ N.

There were no K by N interactions for SLA of plants sampled 15 and 22 DAS (Table 4-10). For plants sampled 15 DAS, K and N did not influence SLA. For plants sampled 22 DAS, SLA increased in quadratic fashion to applied K, and was greatest with 60 $mg \cdot L^{-1}$ K. Specific leaf area was greater when plants were grown with 100 instead of 60 $mg \cdot L^{-1}$ N. For plants sampled 28 DAS, applied K did not influence SLA with 60 $mg \cdot L^{-1}$ N, while with 100 $mg \cdot L^{-1}$ N, SLA increased in linear fashion in response to applied K.

For plants sampled 15 and 28 DAS, applied K did not influence LAR at the 60 $mg \cdot L^{-1}$ N level, but with 100 $mg \cdot L^{-1}$ N, LAR increased in linear fashion to applied K. For plants sampled 22 DAS, there was no K by N interactions for LAR. Applied K did not influence LAR by this sampling date. Leaf area ratio was greater when plants were grown with 100 than with 60 $mg \cdot L^{-1}$ N.

There were no K by N interactions for LMR or RMR of plants sampled 15, 22, and 28 DAS. For plants sampled 15 and 28 DAS, K did not influence either LMR or RMR because neither dry shoot mass nor dry root mass were influenced by added K. For plants sampled 22 DAS, LMR decreased in linear fashion, while RMR increased in linear fashion when K was

applied. Plants grown with 60 $mg \cdot L^{-1}$ N had greater RMRs than those grown with 100 $mg \cdot L^{-1}$ N, regardless of sampling date. Approximately 25 % of lettuce transplant dry matter was allocated to roots when plants were grown with 60 $mg \cdot L^{-1}$ N as compared to 18 % when grown with 100 $mg \cdot L^{-1}$ N. Therefore, lower N concentration in the nutrient solution is recommended.

Root and shoot growth of lettuce transplants were not increased by fertilizer K in Experiment 3. The media contained 24 $mg \cdot kg^{-1}$ water extractable K before fertilizer application. Therefore, sufficient K was probably available or released during the growing cycle for transplant growth.

In general, root and shoot growth of lettuce transplants were not improved by fertilizer K applied via floatation irrigation system to a peat+vermiculite mix. In Experiment 1, leaf tissue K at the end of the experiment ranged from 42 $g \cdot kg^{-1}$ with 0 K to 49 $g \cdot kg^{-1}$ with 60 $mg \cdot L^{-1}$ K. In Experiment 3, leaf tissue analysis at the end of the experiment ranged from 37 $g \cdot kg^{-1}$ with 0 K to 53 $g \cdot kg^{-1}$ with 60 $mg \cdot L^{-1}$ K. Leaf tissue K concentrations were similar in the two experiments, perhaps leading to similar lack of response in root and shoot growth to applied K. Leaf K concentration of about 40 $g \cdot kg^{-1}$ appears to be adequate for production of high quality transplants, with enough roots in 28 days to fill the tray cell volume.

Tremblay and Senécal (1988) reported that root growth and RSR for broccoli, celery, and lettuce were not affected by daily additions of 50 to 350 mg $K \cdot L^{-1}$. Lettuce dry shoot mass increased more sharply in response to increasing K when grown with 350 mg $N \cdot L^{-1}$ than with 150 mg $N \cdot L^{-1}$. In the present work, lettuce shoots did not respond to fertilizer K, regardless of season or fertilizer N concentration.

Root:shoot ratios were not affected by K, regardless of sampling date, or season. Root:shoot ratios ranged from 0.25 to 0.27. In Experiment 3, N led to reduced RSRs probably because the plants produced more shoots and less roots with 100 $mg \cdot L^{-1}$ N than with 60 $mg \cdot L^{-1}$ N. In general, fertilizer K influenced RGR and NAR of plants grown to 21 DAS, but not of plants grown to 28 DAS, perhaps indicating that K was more important earlier in transplant shoot growth.

Regardless of season, approximately 79 % dry matter was partitioned to shoots and 19 % partitioned to roots, implying that temperature differences did not influence dry matter partitioning. These values are similar to those obtained in the P experiments of Chapter 3. Fertilizer K did not influence LMR or RMR because neither dry shoot mass nor dry root mass responded to K.

In Experiment 2, plants grown in peat+rockwool mix (2.5 $mg \cdot kg^{-1}$ water extractable K) responded more to applied K compared with plants grown in peat+vermiculite mix (10.9

$mg \cdot kg^{-1}$ water extractable K) because, unlike vermiculite, rockwool is inherently low in K. In the peat+rockwool mix, applied K led to increases in shoot, root, and leaf growth.

In the present work, fertilizer K was not necessary when a peat+vermiculite media was used, since vermiculite will supply all the K needs for a 28-day growing period when floatation irrigation is used. For a media low in K, applying 60 mg $K \cdot L^{-1}$ resulted in improved root growth, leading to improved pulling success. During periods of low light intensity, increasing light intensity for 16 h improved root growth, resulting in high quality transplants.

Field Experiment

Plants from Greenhouse Experiment 3 were grown to maturity to evaluate the effects of pretransplant K and N on earliness, yield, and lettuce quality.

Plants were harvested in May, 64 days after transplanting. There were no K by N interactions for lettuce head mass (Table 4-11). Pretransplant K and N did not influence lettuce head mass.

There were no K by N interactions for lettuce head firmness, height, diameter, stem width, or core length. Lettuce heads from all K and N treatments were equally firm. Applied K or N did not affect lettuce head height, head diameter, stem width, or core length.

Table 4-11. Effects of K and N nutrition during transplant production on lettuce head mass and head quality characteristics, harvested 3 May 1996.

Nutrient applied	Head mass	Firm rating[z]	Head height	Head diameter	Stem width	Core length	Leaf tissue N	Leaf tissue K
($mg \cdot L^{-1}$)	(g)	(1–5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)	($g \cdot kg^{-1}$)
K								
0	558	4.9	132	109	26	37	33.6	59.0
15	533	5.0	128	106	27	37	32.7	59.5
30	565	5.0	132	108	26	39	33.8	57.7
45	548	4.9	130	113	26	39	32.5	59.8
60	549	5.0	128	107	27	38	30.3	48.4
Response	NS	NS	NS	NS	NS	NS	L*	Q*
N								
60	552	5.0	130	110	26	39	32.9	56.6
100	549	4.9	130	107	26	38	32.3	57.1
Response	NS	NS	NS	NS	NS	NS	NS	NS
K × N	NS	NS	NS	NS	NS	NS	NS	NS

[z]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Linear (L) or quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

There were no K by N interactions for leaf tissue N or leaf tissue K. Leaf tissue N decreased in linear fashion in response to pretransplant K. Pretransplant N did not affect N concentration in plant leaves. Leaf tissue K responded in quadratic fashion to pretransplant K and was least with 60 $mg \cdot L^{-1}$ K. Pretransplant N did not influence K concentration in plant leaves.

Pretransplant K had no effect on posttransplant growth. Therefore, transplants grown with no K in a peat+vermiculite mix with at least 24 $mg \cdot L^{-1}$ water extractable K, produced yields equivalent to transplants grown with 15, 30, 45, or 60 $mg \cdot L^{-1}$ K, when K was applied via floatation irrigation.

Summary

'South Bay' lettuce transplants were produced with different levels of K, different media types, and with extended or supplementary light in an attempt to increase transplant root and shoot growth. Plants were fertigated by floating flats in nutrient solution containing K at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ K, and/or in factorial combination with 60 or 100 $mg \cdot L^{-1}$ N. Plants were exposed to 16 h extended natural photoperiod or to supplementary light for the entire 16 h. The media was either peat+vermiculite or peat+rockwool.

Potassium applied to a peat+vermiculite media via floatation irrigation system had no significant effect on transplant growth. Plant available K in the media (11 to 24 $mg \cdot kg^{-1}$ water extractable K) may have supplied the K needs during lettuce transplant growth and development. Fertilizer K increased shoot and root growth of plants grown in peat+rockwool mix, leading to more transplant pulling success. Plants grown in peat+rockwool mix with no K could not easily be removed from the transplant flat. Supplementary light for 16 h enhanced dry matter production as compared to extension of photoperiod to 16 h. Lettuce growth and yield in the field was not affected by pretransplant K.

This work demonstrated that supplemental K fertilization may not be required in a peat+vermiculite mix using a floatation irrigation system, since vermiculite supplied adequate K. In a peat+rockwool mix, at least 60 $mg \cdot L^{-1}$ K is recommended to produce an ideal transplant with sufficient roots to fill a tray cell and facilitate ease of transplant removal from the transplant flat.

CHAPTER 5

ROOT AND SHOOT GROWTH RESPONDS TO NITROGEN NUTRITION OF LETTUCE TRANSPLANTS

Introduction

Approximately 4,000 ha of crisphead lettuce were grown in Florida during the 1993-94 production season, mostly on the Histosols around Lake Okeechobee and Zellwood (Anon., 1995). However, decline of the Histosols due to oxidation, and competition with other lettuce production areas such as California, have limited lettuce production on the organic soils. Cantliffe (1990) suggested that the expansion of lettuce production into the abundant sandy soils of Florida could increase lettuce production potential in Florida. Commercially acceptable yields of high quality lettuce from sandy soils require new production systems such as plastic mulch and transplants instead of the traditional direct-seeding used on Histosols. Florida growers have, however, been unable to produce lettuce transplants with suitable root development especially using a desirable floatation or subirrigation system. Perhaps proper fertilizer management may result in production of quality lettuce transplants.

Fertilizers can either be applied to transplants independent of irrigation or with the irrigation water (fertigation). When fertigation is employed, careful management of fertilization is important since large amounts of fertilizers, especially N, could be applied when irrigation demands are high, especially where floatation irrigation is employed. If overfertilization occurs with floatation irrigation, there is no method to leach excessive salts.

Tremblay and Senécal (1988) grew lettuce transplants in a growth chamber and overhead irrigated plants daily with distilled water. Fertilization treatments were initiated at emergence and were done to runoff every afternoon, while overhead irrigation was performed every morning. They found that 350 $mg \cdot L^{-1}$ N relative to 150 $mg \cdot L^{-1}$ N increased leaf area and dry shoot mass of lettuce. Specific leaf area of lettuce was not affected by N. Dry root mass and root:shoot ratio (RSR) were reduced by 350 $mg \cdot L^{-1}$ N. By separating irrigation from fertilization, Tremblay and Senécal were constantly leaching salts, something that could not be achieved with the floatation irrigation system.

Masson et al. (1991a) reported that 400 $mg \cdot L^{-1}$ N led to an increase in lettuce dry shoot mass of 38 % compared to applying 100 $mg \cdot L^{-1}$ N. The N treatment was applied twice daily by means of overhead fertigation for a period of 24

days. Lettuce dry root mass and RSR decreased in response to applied N. At harvest, 400 $mg \cdot L^{-1}$ pretransplant N improved marketable head mass by 16 % and also promoted earliness compared to 100 $mg \cdot L^{-1}$ N.

Guzman (1993) reported that lettuce transplants grown with 1200 $mg \cdot L^{-1}$ N applied four times over a 4-week growing period were larger than desired and bruised more during transplanting, resulting in slower recovery in the field from transplant shock. Guzman recommended 900 instead of 1200 $mg \cdot L^{-1}$ N to produce quality lettuce transplants. Kratky and Mishima (1981) reported that daily misting with 230 $mg \cdot L^{-1}$ N in combination with a preplant fertilizer was undesirable since production of excessively tender lettuce transplants, fewer saleable heads, and smaller head size at harvest occurred. They recommended daily misting with 26 $mg \cdot L^{-1}$ N when preplant fertilizer was incorporated or 78 $mg \cdot L^{-1}$ without preplant fertilizer.

Experiments by Tremblay and Senécal (1988) as well as those of Masson et al. (1991a; 1991b) were conducted in Canada, while those of Guzman (1993) and Kratky and Mishima (1981) were conducted in Florida and Hawaii, respectively. Seasonal differences in photoperiod, light, and temperature, and cultural differences in frequency of irrigation and fertilization, as well as location and cultivar differences between the studies may explain why N recommendations for

lettuce transplant growth, vary. In general, 350 to 400 $mg \cdot L^{-1}$ N resulted in reduced root growth (Tremblay and Senécal, 1988; Masson et al., 1991a). Recommendations for optimum N levels for both lettuce transplant root and shoot growth are lacking. Optimizing root growth is important since transplants with well-developed root systems recover more quickly from transplant shock (Weston and Zandstra, 1986), leading to greater earliness, improved head growth, and ultimately higher yields. The exact N nutritional needs for the production of a quality lettuce transplant, remain undefined.

In the present investigation, a range of N concentrations were supplied via floatation irrigation to maximize lettuce transplant root growth in a tray cell, in an attempt to achieve a transplant that pulls from the cell, successfully establishes in the field, and leads to high yields of high quality heads.

Materials and Methods

Greenhouse Experiments

'South Bay' lettuce transplants were grown in a glass greenhouse at the University of Florida, Gainesville, FL. Speedling styrofoam planter flats, model F392A [392 cells of 1.9 × 1.9 × 6.3 cm; 10.9 cm^3 (length × width × depth;

volume)], were used for growing plants. A peat+vermiculite+styrofoam bead mix (1:2:1, v/v/v), with AquaGro wetting agent (Aquatrols, Cherry Hill, NJ) at 0.2 $kg \cdot m^{-3}$, was used for media. Four experiments were conducted during different seasons (Table 5-1). The plants were grown

Table 5-1. Sowing schedule and initial media test (Hanlon et al., 1994) for Experiments 1 to 4.

Expt	Sowing date	Media test[z]						
		pH	EC	NO_3-N	P	K	Ca	Mg
			($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)				
1	1 Sep 1993	4.7	0.9	1.3	12.4	14.6	14.2	11.6
2	19 Nov 1993	4.6	0.1	1.0	1.3	14.3	1.4	3.1
3	30 Jul 1994	4.9	0.4	0.3	1.0	20.0	1.9	4.3
4	10 Sep 1994	4.2	0.3	0.0	2.7	30.5	6.6	16.0

[z]Concentrations in the saturated paste extract.

with natural photoperiod extended to 16 h by 1000-W, high-pressure sodium lamps (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux). A record of cloud cover was kept as an indication of the evaporative demand of the atmosphere. Greenhouse air temperature just above the plant canopy, and media temperatures were recorded by a Series 3020T Datalogger (Electronic Controls Design, Inc., Mulino, OR).

The flats were seeded, covered with a thin layer of vermiculite, overhead irrigated to moisten the vermiculite, and transferred to a cooler at 20 °C for germination. After 48 h, flats were returned to the greenhouse.

Plants were irrigated every two to four days, by floating flats in nutrient solution containing N at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ as NH_4NO_3. The nutrient solution was absorbed by the media by capillary movement. Other nutrients were applied at equivalent rates to all plants and consisted of (in $mg \cdot L^{-1}$) 30 P, 30 K, 100 Ca, and half-strength Hoagland's solution for micronutrients (Hoagland and Arnon, 1950), that was comprised of Mg, S, B, Cu, Cl, Mo, and Zn. The experiments were arranged in a randomized complete-block design with 5 treatments and 4 replications.

Plant samples, 5 per treatment, were taken approximately 14, 21, and 28 days after sowing (DAS) for growth measurements. Measurements included shoot and root fresh and dry mass, and leaf area (measured by a LI-3100 leaf area meter; LI-COR, Lincoln, NE). Growth variables calculated were: root:shoot ratio (RSR = dry root mass ÷ dry shoot mass), relative growth rate (RGR = [ln (final total dry mass) - ln (initial total dry mass) ÷ (final time - initial time)]), net assimilation rate (NAR = [(final total dry mass - initial total dry mass) ÷ (final time - initial time) × {(ln (final leaf area) - ln (initial leaf area)} ÷ (final leaf area - initial leaf area)]), specific leaf area (SLA = leaf area ÷ dry shoot mass), leaf area ratio (LAR = leaf area ÷ total dry mass), leaf mass ratio (LMR = dry shoot mass ÷ total dry mass), and root mass ratio (RMR = dry

root mass ÷ total dry mass) (Hunt, 1978; 1982; Dubik et al., 1992).

Dry shoot samples from the last sampling date were ground to pass a 20-mesh screen and acid-digested for total Kjeldahl N according to Wolf (1982). Briefly, the digestion procedure involved weighing 0.25 g subsamples into 50 mL digestion tubes. Sulfuric acid and 30 % hydrogen peroxide were added to the tubes that were then heated on a digestion block at 375 °C. After the digestion process was completed (a total of 2.5 h), samples were allowed to cool, and deionized water was used to bring the volume to 25 mL. The solutions were filtered through 'P8' filter papers (Fisher brand), with a particle retention of > 25 μm, into 25 mL scintillation vials. The solution samples were then sent to the Analytical Research Laboratory, University of Florida, and N was determined on a 300 Series Rapid Flow Analyzer (ALPKEM Corporation, Wilsonville, OR).

Data were subjected to analysis of variance using the Statistical Analysis System (SAS institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

Field Experiment

Plants from each treatment in Experiment 4 were transplanted into an Arredondo fine sandy soil (loamy,

siliceous, hyperthermic Grosarenic Paleudults) in beds covered with white-on-black polyethylene mulch (0.038 mm thick) at the University of Florida Horticultural Unit, Gainesville, on 14 October 1994. The soil had a water pH of 6.1, with 0.1 $dS \cdot m^{-1}$ for electrical conductivity, and a nutrient content (Hanlon et al., 1994) of (in $mg \cdot kg^{-1}$) 157 P, 50 K, 443 Ca, and 45 Mg (Mehlich-1 extractant). The experiment was a randomized complete-block design with treatments replicated four times. Preplant fertilizer (13N-0P-10.8K) was applied broadcast and incorporated in the bed at 230 $kg \cdot ha^{-1}$. Raised beds spaced 1.2 m center to center, were fumigated with methyl bromide and then covered with the polyethylene mulch. Plots consisted of 80 plants, planted on double offset rows, spaced 0.3 m between plants and between rows on the bed (equivalent to 54,000 plants per ha).

Plants from the 0 N treatment were too small to transplant. Just after transplanting, 100 mL of nutrient solution (150 $mg \cdot L^{-1}$ 20N-8.6P-16.7K) was applied to each transplant hole as a starter fertilizer. Water was applied twice daily for 20 min each cycle, using drip irrigation lines placed on the center of the bed with emitters spaced 0.3 m apart. Tensiometers (Irrometer Company, Inc., Riverside, CA) were used to monitor soil moisture adequacy in the beds. The root zone area was maintained at approximately -10 kPa according to Hochmuth and Clark

(1991). Starting one week after transplanting, fertilizer at a rate of 15 kg·ha^{-1} N and 16 kg·ha^{-1} K, supplied from NH_4NO_3 and KNO_3, was injected once weekly using a venturi pump (Netafim Irrigation, Altamonte Springs, FL), with the last application one week before harvest to give a total amount of 150 kg·ha^{-1} N and 180 kg·ha^{-1} K. Cultural management practices were similar to those used commercially in Florida (Hochmuth et al., 1988).

To determine optimum lettuce head maturity among the treatments, plants were harvested 53, 56, and 59 days after transplanting. At each harvest, 20 plants in a plot were cut, individually weighed, and then 10 heads were assessed for firmness, cut longitudinally for height, diameter, stem width, and core length measurements. Wrapper leaves were sampled a week before harvest for analysis of total Kjeldahl N as previously described for greenhouse experiments. Data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear and quadratic polynomial contrasts.

Results and Discussion

Greenhouse Experiments

Experiment 1 was conducted during the fall, under greenhouse temperatures ranging from 14 to 34 °C (Fig. 5-1). The average daily maximum media temperature was 32 °C, while the average daily minimum media temperature was 21 °C. During the course of the trial, there were totals of 18 sunny days and 8 cloudy days.

Fresh and dry shoot mass were least with 0 N and greatest with 60 $mg \cdot L^{-1}$ N, regardless of sampling date (Table 5-2). For plants sampled 15 DAS, fresh shoot mass increased in quadratic fashion in response to applied N, while for plants sampled 22 and 28 DAS, there was a positive linear response of fresh shoot mass to applied N. For plants sampled 15 and 22 DAS, there was a positive linear response of dry shoot mass to applied N, while for plants sampled 28 DAS, dry shoot mass increased in quadratic fashion in response to applied N.

For plants sampled 15, 22, and 28 DAS, fresh root mass increased in quadratic fashion in response to applied N. Fresh root mass was greatest with 15 $mg \cdot L^{-1}$ N, 15 DAS. Nitrogen did not influence dry root mass by this sampling date. For plants sampled 22 and 28 DAS, dry root mass

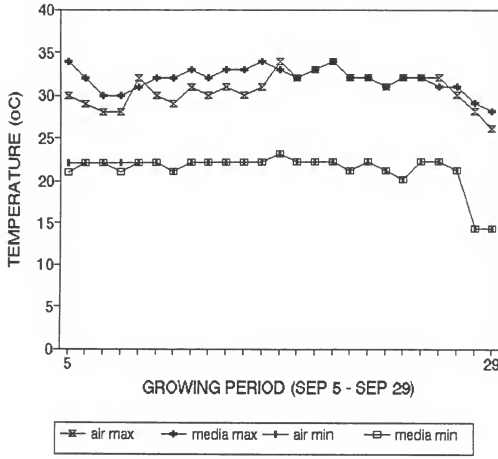


Fig. 5-1. Maximum and minimum air and media temperature during transplant production for Experiment 1, September 1993.

Table 5-2. Root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 1, September 1993.

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)	Root: shoot ratio
			15 Days After Sowing				
0	40	2.5	29	1.5	1.5		0.60
15	104	5.5	44	1.8	4.1		0.36
30	154	6.1	38	1.5	6.4		0.26
45	194	6.9	39	1.7	8.3		0.25
60	196	6.9	36	1.8	8.4		0.34
Response	Q**	L**	Q**	NS	Q**		Q*
			22 Days After Sowing				
0	55	4.0	47	3.0	2.3		0.77
15	162	12.0	79	5.2	7.2		0.44
30	275	17.8	93	5.4	11.8		0.30
45	429	24.8	128	7.2	17.9		0.29
60	551	30.5	113	5.8	22.8		0.19
Response	L**	L**	Q**	Q**	L**		Q**
			28 Days After Sowing				
0	64	7.4	48	5.5	2.8	6.5	0.75
15	229	22.9	110	11.9	9.6	6.0	0.52
30	387	36.5	153	14.5	16.7	10.5	0.40
45	587	46.5	195	16.0	24.7	12.7	0.34
60	712	55.2	200	15.5	30.0	14.6	0.28
Response	L**	Q*	Q**	Q**	L**	L**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

increased in quadratic fashion in response to applied N. Dry root mass was least with 0 N and greatest with 45 $mg \cdot L^{-1}$ N. Added N increased shoot mass to a greater extent than root mass.

Leaf area and fresh shoot mass response to applied N were similar (Table 5-2). For plants sampled 28 DAS, there was a positive linear response of leaf tissue N to applied N. Leaf tissue N was least in plants grown with 0 or 15 $mg \cdot L^{-1}$ N, and greatest in plants grown with 60 $mg \cdot L^{-1}$ N, 28 DAS. In general, RSR values decreased in quadratic fashion to applied N, regardless of sampling date. With 0 N, there were greater RSR values, but the plants were extremely small for transplanting to the field. Aloni et al. (1991) reported that under low N levels, sucrose exported to the roots was rapidly hydrolyzed to support growth, presumably due to enhanced invertase activity.

There was a positive linear response of RGR to applied N for plants grown to 22 DAS, but RGR values were unaffected by N for plants grown to 28 DAS (Table 5-3). For plants grown to 22 DAS, NAR values were not influenced by applied N. However, for plants grown to 28 DAS, there was a negative linear response of NAR to applied N. Although NAR was greater in plants grown with 0 N, the total production of dry matter per plant over the same period was much greater in plants grown with added N.

Table 5-3. Influence of N nutrition on growth characteristics of lettuce transplants for Experiment 1, September 1993.

Nitrogen applied ($mg \cdot L^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			15 Days After Sowing			
0			0.62	0.39	0.63	0.37
15			0.82	0.60	0.74	0.26
30			1.08	0.86	0.80	0.20
45			1.22	0.97	0.80	0.20
60			1.51	1.07	0.76	0.24
Response			L*	L**	Q*	Q*
			22 Days After Sowing			
0	0.58	1.62	0.96	0.43	0.57	0.43
15	0.89	1.82	1.40	0.68	0.70	0.30
30	1.12	1.75	2.02	1.04	0.77	0.23
45	1.32	1.88	2.63	1.27	0.78	0.23
60	1.49	1.93	4.35	1.89	0.84	0.16
Response	L**	NS	L**	L**	Q*	Q*
			28 Days After Sowing			
0	0.61	2.31	0.69	0.21	0.57	0.43
15	0.70	2.12	0.80	0.27	0.66	0.34
30	0.79	1.97	0.94	0.33	0.72	0.28
45	0.67	1.44	1.00	0.40	0.74	0.26
60	0.66	1.30	0.99	0.43	0.78	0.22
Response	NS	L**	Q*	L**	Q**	Q**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**),or nonsignificant (NS).

Both SLA and LAR increased in response to applied N, regardless of sampling date (Table 5-3). There was a positive linear response of SLA to applied N for plants sampled 15 and 22 DAS. For plants sampled 28 DAS, SLA increased in quadratic fashion to applied N. Leaf area ratios increased in linear fashion to applied N, regardless of sampling date. The reduction in SLA and LAR for plants grown with 0 N reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

Leaf mass ratio increased in quadratic fashion, while RMR decreased in quadratic fashion to applied N, for plants sampled 15, 22, and 28 DAS. Although both shoot and root mass increased in response to applied N, the increase in shoot mass was greater than root mass, resulting in lower RMR values. Plants grown with 0 N allocated approximately 57 % of the dry matter to shoots and 43 % to roots, 28 DAS, while plants grown with 60 $mg \cdot L^{-1}$ N allocated approximately 78 % of dry matter to shoots and only 22 % went to roots, indicating that added N shifted dry matter partitioning from roots to shoots. Nitrogen was important for building a bigger plant, but shoot biomass production was favored over root biomass production.

Experiment 1 indicated that at least 60 $mg \cdot L^{-1}$ N supplied via floatation irrigation, was required for

increased transplant root and shoot growth in a peat+vermiculite mix low in NO_3-N.

In order to further test this conclusion, Experiment 2 was conducted during the winter instead of fall, under greenhouse temperatures ranging from 6 to 27 °C (Fig. 5-2). The average daily maximum media temperature was 23 °C, while the average daily minimum media temperature was 11 °C. During the course of the experiment, there were totals of 19 sunny days and 8 cloudy days, with rain during two of the cloudy days.

For plants sampled 15 DAS, fresh shoot mass increased in quadratic fashion in response to applied N (Table 5-4). Fresh shoot mass was least for plants grown with 0 N and greatest for plants grown with 60 $mg \cdot L^{-1}$ N. For plants sampled 21 and 28 DAS, there was a positive linear response of fresh shoot mass to applied N. Dry shoot mass increased in quadratic fashion in response to applied N for plants sampled 15, 21, and 28 DAS.

Fresh root mass increased in quadratic fashion for plants sampled 15, 21, and 28 DAS. Fresh root mass of plants sampled 15 DAS increased in response to applied N from 0 to 30 $mg \cdot L^{-1}$, thereafter fresh root mass was unaffected. There was a positive linear response of dry root mass to applied N for plants sampled 15 and 21 DAS. For plants sampled 28 DAS, dry root mass increased in quadratic fashion in response to

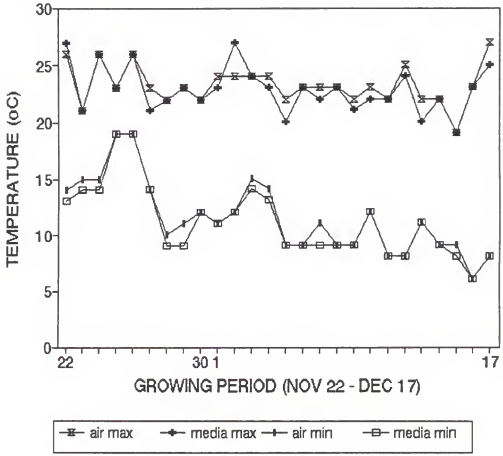


Fig. 5-2. Maximum and minimum air and media temperature during transplant production for Experiment 2, November/December 1993.

Table 5-4. Root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 2, Nov/Dec 1993.

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)	Root: shoot ratio
			15 Days After Sowing				
0	44	3.9	37	0.7	1.8		0.17
15	106	6.5	54	1.2	4.1		0.18
30	170	9.1	62	1.8	6.3		0.20
45	233	11.3	58	2.6	8.6		0.23
60	265	11.4	63	2.6	9.7		0.23
Response	Q*	Q**	Q*	L**	Q*		NS
			21 Days After Sowing				
0	61	8.4	51	4.4	2.1		0.53
15	175	16.6	92	6.9	6.3		0.42
30	323	27.7	121	8.5	11.6		0.31
45	442	32.1	142	9.5	16.0		0.30
60	547	38.2	165	11.3	18.9		0.30
Response	L**	Q*	Q*	L**	Q*		Q**
			28 Days After Sowing				
0	68	9.7	62	5.5	2.4	7.0	0.58
15	280	33.0	143	10.7	9.7	10.0	0.33
30	468	46.9	185	14.0	16.5	12.8	0.30
45	689	55.7	217	15.8	24.5	15.9	0.28
60	909	66.8	250	15.4	31.5	17.4	0.23
Response	L**	Q*	Q*	Q**	L**	L**	Q*

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

applied N. Dry root mass was least for plants grown with 0 N, regardless of sampling date. Leaf area and fresh shoot mass response to applied N were similar. For plants sampled 28 DAS, leaf tissue N increased in linear fashion in response to applied N. Root:shoot ratios of plants sampled 15 DAS were unaffected by applied N. For plants sampled 21 and 28 DAS, RSR values decreased in quadratic fashion to applied N, indicating once again that added N caused more dry matter to be partitioned into shoots rather than to roots.

Relative growth rate of plants grown to 21 DAS was unaffected by N (Table 5-5). For plants grown to 28 DAS, RGR responded in quadratic fashion to applied N, and was least for plants grown with 0 N and greatest for plants grown with 15 $mg \cdot L^{-1}$ N. For plants grown to 21 or 28 DAS, NAR responded in quadratic fashion to applied N. In general, NAR of plants grown to 21 DAS decreased at all levels of applied N, but was greatest in plants grown with 15 $mg \cdot L^{-1}$ N, 28 DAS.

For plants sampled 15 and 28 DAS, SLA and LAR increased in linear fashion in response to applied N. For plants sampled 21 DAS, SLA and LAR increased in quadratic fashion to applied N. Specific leaf area and LAR of plants at 21 DAS increased in response to applied N from 0 to 45 $mg \cdot L^{-1}$, thereafter SLA and LAR were unaffected. The reduction in SLA and LAR for plants grown with 0 N reflects the reduction in

Table 5-5. Influence of N nutrition on growth characteristics of lettuce transplants for Experiment 2, November/December 1993.

Nitrogen applied ($mg \cdot L^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
		15 Days After Sowing				
0			0.48	0.41	0.86	0.14
15			0.64	0.54	0.85	0.15
30			0.69	0.58	0.84	0.16
45			0.76	0.61	0.81	0.19
60			0.85	0.69	0.81	0.19
Response			L**	L**	NS	NS
		21 Days After Sowing				
0	1.08	4.35	0.25	0.16	0.66	0.34
15	1.13	3.11	0.38	0.27	0.71	0.29
30	1.20	2.93	0.42	0.32	0.77	0.23
45	1.10	2.34	0.50	0.38	0.77	0.23
60	1.26	2.58	0.50	0.38	0.77	0.23
Response	NS	Q*	Q**	Q**	Q**	Q**
		28 Days After Sowing				
0	0.17	1.08	0.25	0.16	0.64	0.36
15	0.62	2.59	0.30	0.22	0.76	0.24
30	0.52	1.78	0.35	0.27	0.77	0.23
45	0.54	1.52	0.44	0.34	0.78	0.22
60	0.50	1.35	0.48	0.39	0.81	0.19
Response	Q**	Q**	L**	L**	Q*	Q*

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

both leaf size and assimilate production (Dubik et al., 1990).

For plants sampled 15 DAS, LMR and RMR were unaffected by added N. For plants sampled 21 and 28 DAS, LMR increased in quadratic fashion, while RMR decreased in quadratic fashion in response to applied N. Plants grown with 0 N allocated approximately 64 % of the dry matter to shoots and 36 % to roots, 28 DAS, while plants grown with 60 $mg \cdot L^{-1}$ N allocated approximately 81 % of dry matter to the shoots and only 19 % went to roots. Twice as much dry matter was allocated to roots when plants were grown with 0 N than with 60 $mg \cdot L^{-1}$ N. Similar results were obtained in Experiment 1 (fall), indicating that temperature differences did not alter dry matter allocation between shoots and roots.

Once again, 60 $mg \cdot L^{-1}$ N, supplied via floatation irrigation to a peat+vermiculite media low in NO_3-N, led to more shoot and root growth.

Experiment 3 was conducted during the summer, instead of fall or winter, under greenhouse temperatures ranging from 19 to 39 °C (Fig. 5-3). The average daily maximum media temperature was 31 °C, while the average daily minimum media temperature was 20 °C. During the course of the experiment, there were totals of 18 sunny and 10 cloudy days, with rain during six of the cloudy days.

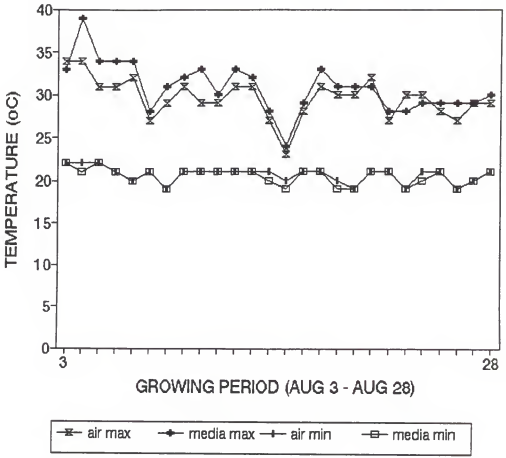


Fig. 5-3. Maximum and minimum air and media temperature during transplant production for Experiment 3, August 1994.

For plants sampled 15, 22 and 29 DAS, fresh and dry shoot mass increased in linear fashion in response to applied N (Table 5-6). For plants sampled 15 and 29 DAS, fresh root mass increased in linear fashion to applied N. Fresh root mass of plants sampled 22 DAS increased in quadratic fashion to applied N. Fresh root mass increased in response to applied N from 0 to 45 $mg \cdot L^{-1}$, thereafter fresh root mass was unaffected. Dry root mass was least for plants grown with 0 N and greatest for plants grown with 60 $mg \cdot L^{-1}$ N, regardless of sampling date. For plants sampled 15 DAS, there was a positive linear response of dry root mass to applied N, while for plants sampled 22 and 29 DAS, dry root mass increased in quadratic fashionin response to applied N.

For plants sampled 15, 22, and 29 DAS, leaf area increased in linear fashion to applied N. Leaf area and fresh shoot mass responses to applied N were similar. For plants sampled 29 DAS, leaf tissue N increased in quadratic fashion in response to applied N. Leaf N concentration was least in plants grown with 0 N, and greatest in plants grown with 60 $mg \cdot L^{-1}$ N. Therefore, leaf tissue N was related to increased root and shoot growth. Root:shoot ratios of plants sampled 15, 22, and 29 DAS decreased in quadratic fashion to applied N. With 0 N, there were greater RSR values, but the plants were extremely small for transplanting to the field. Aloni et al. (1991) reported that under low N levels,

Table 5-6. Root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 3, August 1994.

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)	Root: shoot ratio
			15 Days After Sowing				
0	40	4.6	41	3.0	1.4		0.66
15	108	8.3	50	3.5	4.1		0.43
30	173	11.8	64	4.5	7.2		0.38
45	224	13.9	77	4.6	8.9		0.33
60	292	16.8	62	5.1	12.1		0.31
Response	L**	L**	L*	L**	L**		Q**
			22 Days After Sowing				
0	52	7.0	49	4.7	1.8		0.67
15	184	17.1	112	9.0	6.3		0.53
30	330	27.2	132	10.7	12.6		0.39
45	450	34.1	159	11.7	17.7		0.34
60	599	43.6	154	12.6	24.2		0.29
Response	L**	L**	Q*	Q**	L**		Q**
			29 Days After Sowing				
0	61	9.3	56	6.0	1.9	6.3	0.65
15	267	28.9	139	14.0	9.0	10.6	0.49
30	488	45.4	189	19.3	17.8	12.7	0.43
45	725	61.7	279	20.8	27.9	14.6	0.34
60	960	72.6	302	22.3	36.6	17.3	0.31
Response	L**	L**	L**	Q**	L**	Q*	Q*

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**).

sucrose exported to the roots was rapidly hydrolyzed to support growth, presumably due to enhanced invertase activity.

For plants grown to 22 or 29 DAS, RGR increased in quadratic fashion in response to applied N (Table 5-7). However, the RGR values were lower by 29 than by 22 DAS. For plants grown to 22 or 29 DAS, NAR decreased in linear fashion to applied N. Net assimilation rates were least with 60 $mg \cdot L^{-1}$ N, but the total dry matter production was much greater at this N level compared to other N levels.

For plants sampled 15 and 22 DAS, SLA and LAR increased in quadratic fashion to applied N, while for plants sampled 29 DAS, SLA and LAR increased in linear fashion to applied N. The reduction in SLA and LAR for plants grown with 0 N reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

Leaf mass ratio increased in quadratic fashion, while RMR decreased in quadratic fashion in response to applied N, for plants sampled 15 and 22 DAS. For plants sampled 29 DAS, LMR increased in linear fashion, while RMR decreased in linear fashion in response to applied N. Plants grown with 0 N allocated approximately 61 % of the dry matter to shoots and 39 % to roots, 29 DAS, while plants grown with 60 $mg \cdot L^{-1}$ N allocated approximately 77 % of dry matter to shoots and only 23 % went to roots, indicating once again that added N

Table 5-7. Influence of N nutrition on growth characteristics of lettuce transplants for Experiment 3, August, 1994.

Nitrogen applied ($mg \cdot L^{-1}$)	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
		15 Days After Sowing				
0			0.30	0.18	0.60	0.40
15			0.50	0.35	0.70	0.30
30			0.61	0.44	0.72	0.28
45			0.64	0.48	0.75	0.25
60			0.73	0.56	0.77	0.23
Response			Q**	Q**	Q**	Q**
		22 Days After Sowing				
0	0.43	2.62	0.26	0.15	0.60	0.40
15	0.78	2.76	0.38	0.24	0.65	0.35
30	0.85	2.24	0.46	0.33	0.72	0.28
45	0.91	2.15	0.52	0.38	0.74	0.26
60	0.94	1.96	0.56	0.43	0.78	0.22
Response	Q*	L*	Q**	Q**	Q*	Q*
		29 Days After Sowing				
0	0.26	1.92	0.20	0.12	0.61	0.39
15	0.50	2.22	0.31	0.21	0.67	0.33
30	0.53	1.77	0.39	0.28	0.70	0.30
45	0.58	1.63	0.45	0.34	0.75	0.25
60	0.52	1.28	0.51	0.39	0.77	0.23
Response	Q*	L*	Q**	L**	L**	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**).

shifted dry matter partitioning from roots to shoots. Nitrogen was important for building a bigger plant, but shoot biomass production was favored over root biomass production.

Once again, the highest N level used (60 $mg \cdot L^{-1}$), supplied via floatation irrigation to a peat+vermiculite media low in NO_3-N, led to more shoot and root growth.

Neither of the experiments conducted so far were carried to the field. Experiment 4 was conducted to evaluate the effects of N on transplant growth and subsequent yield and lettuce quality in the field.

Experiment 4 was conducted during the fall, similar to Experiment 2, under greenhouse temperatures ranging from 14 to 33 °C (Fig. 5-4). The average daily maximum media temperature was 28 °C, while the average daily minimum media temperature was 19 °C. During the course of the experiment, there were totals of 15 sunny and 13 cloudy days, with rain during seven of the cloudy days.

For plants sampled 15 DAS, fresh and dry shoot mass increased in quadratic fashion to applied N (Table 5-8). Fresh and dry shoot mass were least with 0 N and greatest with 60 $mg \cdot L^{-1}$ N. For plants sampled 22 and 29 DAS, fresh and dry shoot mass increased in linear fashion in response to applied N. For plants sampled 15 and 22 DAS, fresh root mass increased in quadratic fashion in response to applied

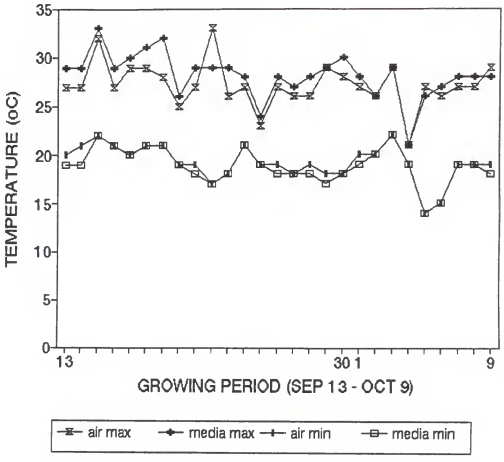


Fig. 5-4. Maximum and minimum air and media temperature during transplant production for Experiment 4, September/October 1994.

Table 5-8. Root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 4, September/October 1994.

Nitrogen applied ($mg \cdot L^{-1}$)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Plant height (mm)	Stem diameter (mm)	Leaf tissue N ($g \cdot kg^{-1}$)
				15 Days After Sowing				
0	41	3.9	22	1.9	1.5	20.5		
15	123	8.1	55	4.0	4.9	36.1		
30	217	12.9	69	4.9	9.2	46.3		
45	293	17.0	83	5.1	12.0	59.4		
60	338	17.8	64	5.2	13.9	66.1		
Response	Q*	Q**	Q*	Q**	Q*	Q**		
				22 Days After Sowing				
0	59	7.9	45	4.4	1.9	21.5		
15	185	16.5	103	9.0	6.8	36.8		
30	350	27.5	142	11.1	13.1	50.3		
45	475	33.4	160	11.8	18.4	59.2		
60	629	37.7	170	12.3	23.8	69.6		
Response	L**	L**	Q**	Q**	L**	Q**		
				29 Days After Sowing				
0	74	10.7	51	6.1	2.3	21.7	1.3	4.9
15	266	28.5	135	13.7	9.9	34.9	1.8	8.8
30	488	44.0	191	18.0	18.6	54.3	2.0	11.1
45	734	54.8	217	18.4	29.3	70.2	2.2	14.6
60	942	63.7	249	20.1	36.7	78.0	2.3	17.4
Response	L**	L**	L**	Q**	L**	L**	Q*	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*) or 0.01 (**).

N. There was a positive linear response of fresh root mass to applied N for plants sampled 29 DAS. For plants sampled 15, 22, and 29 DAS, dry root mass increased in quadratic fashion in response to applied N. Fresh and dry root mass were least in plants grown with 0 N, regardless of sampling date. Leaf area, transplant height, transplant stem diameter, leaf tissue N, and fresh and dry shoot and root mass responses to applied N were similar.

For plants sampled 15, 22, and 29 DAS, RSR values decreased in linear fashion in response to applied N (Table 5-9). With 0 N, there were greater RSR values, but the plants were extremely small. Aloni et al. (1991) reported that under low N levels, sucrose exported to the roots was rapidly hydrolyzed to support growth, presumably due to enhanced invertase activity.

Applied N did not influence RGR values for plants grown to 22 DAS. For plants grown to 29 DAS, RGR increased in linear fashion in response to applied N. For plants grown to 22 DAS, NAR values decreased in quadratic fashion, while for plants grown to 29 DAS, NAR decreased in linear fashion in response to applied N. Although NAR was greater in plants grown with 0 N, the total production of dry matter per plant over the same period was much greater in plants grown with added N.

Table 5-9. Influence of N nutrition on growth characteristics of lettuce transplants for Experiment 4, September/October 1994.

Nitrogen applied ($mg \cdot L^{-1}$)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			15 Days After Sowing				
0	0.48			0.39	0.27	0.68	0.32
15	0.49			0.60	0.40	0.67	0.33
30	0.39			0.72	0.52	0.72	0.28
45	0.30			0.70	0.54	0.77	0.23
60	0.29			0.78	0.61	0.78	0.22
Response	L**			Q**	Q**	L**	L**
			22 Days After Sowing				
0	0.57	0.76	3.83	0.24	0.15	0.64	0.36
15	0.55	0.74	2.32	0.41	0.27	0.65	0.35
30	0.41	0.77	1.88	0.48	0.34	0.71	0.29
45	0.36	0.71	1.55	0.55	0.41	0.74	0.26
60	0.33	0.76	1.45	0.64	0.48	0.75	0.25
Response	L**	NS	Q**	L**	L**	L**	L**
			29 Days After Sowing				
0	0.57	0.31	2.15	0.22	0.14	0.64	0.36
15	0.48	0.50	2.02	0.35	0.24	0.68	0.32
30	0.41	0.47	1.46	0.43	0.30	0.71	0.29
45	0.34	0.48	1.20	0.54	0.40	0.75	0.25
60	0.32	0.52	1.14	0.58	0.44	0.76	0.24
Response	L**	L*	L**	Q*	L**	L**	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

For plants sampled 15 DAS, SLA and LAR increased in quadratic fashion in response to applied N (Table 5-9). There was a positive linear response of SLA and LAR to applied N for plants sampled 22 DAS. For plants sampled 29 DAS, SLA increased in quadratic fashion, while LAR increased in linear fashion to applied N. The reduction in SLA and LAR for plants grown with 0 N reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

For plants sampled 15, 22 and 29 DAS, LMR increased in linear fashion, while RMR decreased in linear fashion in response to applied N. Plants grown with 0 N allocated approximately 64 % of the dry matter to shoots and 36 % to roots, 29 DAS, while plants grown with 60 $mg \cdot L^{-1}$ N allocated approximately 76 % of dry matter to shoots and only 24 % went to roots, indicating that added N shifted dry matter partitioning from roots to shoots. Nitrogen was important for building a bigger plant, but shoot biomass production was favored over root biomass production. Similar results were reported by Dufault (1985) for celery transplants.

The four sowing dates were used in an attempt to assess the consistency of N treatment effect with time. Average daily maximum media temperatures were 32, 23, 31, and 28 °C, while average daily minimum temperatures were 21, 11, 20, and 19 °C for Experiments 1, 2, 3, and 4, respectively. Fresh and dry shoot mass, and fresh root mass were similar

among the four experiments, indicating that temperature and light variations (as long as photoperiod was extended to 16 h) had minimal influence on growth. On the other hand, N nutrition had a great impact on lettuce transplant root and shoot growth.

Leaf tissue N values increased in response to applied N, regardless of season. In Experiment 1, leaf tissue N ranged from approximately 6 to 15 $g \cdot kg^{-1}$, while in the other 3 experiments, it ranged from 6 to 17 $g \cdot kg^{-1}$. Although both shoot and root mass increased in response to applied N, the increase in shoot mass was greater than root mass, resulting in lower values of RSR and RMR. By the last sampling date, RSR values ranged from 0.57 to 0.75 with 0 N, and from 0.23 to 0.32 with 60 $mg \cdot L^{-1}$ N. These values were, therefore, relatively similar regardless of season. Relative growth rate, NAR, SLA, LAR, and LMR increased in response to applied N, indicating improved growth with N.

It was observed that transplants could not be easily pulled from the transplant flat at all levels of applied N in these experiments. When the mean dry root mass was less than 20 mg, pulling success was observed to be even more reduced. Nitrogen at 60 $mg \cdot L^{-1}$ N was perhaps not adequate with the irrigation programs used. Therefore, additional experiments (Chapter 6) were designed to investigate the

effect of N fertilization to 120 $mg \cdot L^{-1}$ and fertigation frequency on lettuce transplant growth and development.

Masson et al. (1991a) reported that 400 $mg \cdot L^{-1}$ N improved lettuce transplant shoot growth compared to 100 $mg \cdot L^{-1}$, but adversely affected dry root mass and RSRs. Tremblay and Senécal (1988) reported that 350 $mg \cdot L^{-1}$ enhanced lettuce transplant shoot growth compared to 150 $mg \cdot L^{-1}$ N, but reduced dry root mass. The present experiments have demonstrated that for lettuce transplant promote root growth promotion, lower levels of N than reported by these authors seemed appropriate.

Field Experiment

To determine the influence of transplant conditioning on harvest maturity, plants from Experiment 4 were planted in the field. The optimum time to harvest was determined to be 56 days after transplanting (DAT) as previously described in the Materials and Methods. After the first harvest at 53 DAT (Appendix Table C-9), plants still continued to increase in mass up to 56 DAT. Thereafter, there was no appreciable increase in head mass, and some lettuce heads started splitting because they were overmature. Lettuce heads at 59 DAT were also of poor quality due to elongated cores. Therefore, only results at 56 DAT will be discussed.

Lettuce head mass increased in linear fashion in response to pretransplant N (Table 5-10). The least head mass was obtained in plants grown with 15 $mg \cdot L^{-1}$ N, while the heaviest heads were from plants grown with 60 $mg \cdot L^{-1}$ N, even though all treatments received the same postplant N fertilizers and no differences in tissue N among treatments were found at harvest. Transplants grown with 60 $mg \cdot L^{-1}$ N had the greatest shoot and root mass, 29 DAS. Therefore, the bigger the plant at planting, the greater the yield. Similar results were presented in Chapters 3 and 4. In those experiments, not only did bigger plants improve yield, but also promoted early maturity. This is of particular significance in northern Florida where the growing period is shortened by either low or high temperatures. Low temperatures (fall plantings) could result in lettuce heads freezing, while high temperatures (spring plantings) could result in premature bolting. Masson et al. (1991b) reported that 400 $mg \cdot L^{-1}$ N improved lettuce head mass at harvest and promoted early maturity compared to 100 $mg \cdot L^{-1}$. However, N at 400 $mg \cdot L^{-1}$ adversely affected dry root mass and RSRs (Masson et al., 1991a).

Pretransplant N did not influence head firmness or head diameter. Head height and core length increased in quadratic fashion to pretransplant N. Stem width increased in linear fashion to pretransplant N. The response of stem width and

Table 5-10. Effects of N nutrition during transplant production on lettuce head mass and head quality characteristics, harvested 9 December 1994.

Nitrogen applied	Head mass	Firm rating[z]	Head height	Head diameter	Stem width	Core length	Leaf tissue N
($mg \cdot L^{-1}$)	(g)	(1-5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)
15	566	4.7	111	123	21	40	38.4
30	649	4.8	119	126	22	46	38.6
45	649	4.8	117	127	23	45	37.4
60	666	4.8	119	125	23	44	38.6
Response	L*	NS	Q*	NS	L*	Q*	NS

[z]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

core length to pretransplant N paralleled the response of lettuce head mass and head height to pretransplant N, respectively.

At harvest, tissue N levels were equal regardless of pretransplant N applied. Hochmuth et al. (1991) reported values of 20 to 30 $g \cdot kg^{-1}$ (soil type not reported) to be indicative of an adequate range for crisphead lettuce. The values of tissue N in this experiment were about 38 $g \cdot kg^{-1}$, indicating that sufficient N was supplied to the plants.

The present work demonstrated that added N up to 60 $mg \cdot L^{-1}$ improved shoot and root growth, leading to a bigger transplant. A bigger plant (approximately 80 mm tall, with fresh shoot mass of 950 mg and fresh root mass of 250 mg) at transplanting led to earliness and improved head mass at harvest.

Summary

'South Bay' lettuce transplants were produced with different levels of N to evaluate how much N was necessary to produce high quality transplants, and subsequent high quality crop in the field. In this study, a quality or ideal transplant was one which could be produced in the shortest period of time, having sufficient roots to fill a tray cell to facilitate ease of pulling from the transplant flat.

Plants were fertigated by floating flats in nutrient solution containing N at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$. To avoid inconsistency in the duration of the light period, natural photoperiod was extended to 16 h.

Increasing N from 0 to 60 $mg \cdot L^{-1}$ resulted in greater transplant shoot and root mass. The increase in shoot mass was much greater than for root mass, resulting in lower values of RSR and RMR due to applied N. Relative growth rate, SLA, LAR, and LMR, increased with applied N, suggesting improved transplant growth at higher N levels. Growth responses of lettuce transplant shoots and roots to applied N were consistent, regardless of season or stage of growth. Leaf tissue N always was increased by applied N.

Lettuce head mass was improved at harvest by pretransplant N. The heaviest heads were obtained from plants grown with 60 $mg \cdot L^{-1}$ in the greenhouse. In the greenhouse, transplants grown with 60 $mg \cdot L^{-1}$ also had the greatest shoot and root mass, RSR of approximately 0.3, and leaf tissue N of about 17 $g \cdot kg^{-1}$. Since transplants at all levels of N could not be easily pulled from the transplant flat, further investigations are needed to relate pull force and pulling success to N nutrition of transplants.

This work demonstrated that at least 60 $mg \cdot L^{-1}$ N supplied via floatation irrigation, was required for improved transplant shoot and root growth in a

peat+vermiculite mix low in NO_3-N. Transplants grown with 60 $mg \cdot L^{-1}$ N compared to 15 $mg \cdot L^{-1}$ N, were bigger at transplanting and resulted in improved head mass at harvest.

CHAPTER 6

PROMOTION OF LETTUCE TRANSPLANT ROOT DEVELOPMENT BY PROPER MANAGEMENT OF NITROGEN AND IRRIGATION

Introduction

Unsatisfactory results in stand establishment of direct-seeded lettuce crops using both pelleted and raw seed, particularly during conditions of environmental stress, has led to the use of transplants as a means of establishing economically viable plant stands (Cliffe, 1989). Guzman et al. (1989) found that superior plant stand was the major factor resulting in increased marketable yields from transplanted crisphead and romaine lettuce. They concluded that perhaps growers in south Florida, with harsh and unreliable weather, could minimize economic losses and become more reliable suppliers of lettuce if a portion of the lettuce crop was transplanted. According to Klassen (1986), other reasons growers were transplanting rather than direct-seeding included better plant-to-plant uniformity especially for a once-over harvested crop such as lettuce, early season weed control, more precise spacing of plants, and elimination of the need to thin densely seeded rows.

Containerized vegetable transplants grown in greenhouses can either be overhead irrigated, or subirrigated. Using subirrigation (floatation system), Leskovar and Cantliffe (1993) improved uniformity and quality of pepper transplants, compared to using overhead irrigation. When drought stress and root pruning methods were used to harden and prevent stem elongation in fresh-market tomato transplants grown with a floatation system, an increase in lateral root elongation and a decrease in shoot:root ratio were reported (Leskovar et al., 1994). A reduction in shoot:root ratio and an improvement in water-use efficiency of pepper transplants were also reported by Leskovar and Heineman (1994) when plants were produced via the floatation system of irrigation.

However, growers have not been able to produce the highest quality lettuce transplants on a seasonal basis using the floatation system. A well developed root system is essential so that transplants can be easily pulled from the transplant flat, or pushed out utilizing a mechanical transplanter. If shoots are too long, the plants will tend to fall over, resulting in easily damaged plants and scorched leaves especially when transplanted onto plastic-mulched beds. If shoots are too short, they cannot be easily handled and can be trapped under plastic mulch. When using the floatation system of irrigation, careful management of

fertilization is important since large amounts of fertilizers, especially N, can greatly increase lettuce transplant shoot growth at the expense of root growth (Tremblay and Senécal, 1987; 1988; Masson et al., 1991a).

This study was conducted (a) to determine the optimum fertigation frequency and optimum N concentration for maximizing lettuce transplant root growth when N was supplied via the floatation irrigation system, and (b) to determine if N applied at different times during transplant growth, was a factor in promoting root growth.

Materials and Methods

Greenhouse Experiments

'South Bay' lettuce transplants were grown in a glass greenhouse at the University of Florida, Gainesville, FL. Speedling styrofoam planter flats, model F392A [392 cells of 1.9 × 1.9 × 6.3 cm; 10.9 cm^3 (length × width × depth; volume)], were used for growing plants. A peat+vermiculite+styrofoam bead mix (1:2:1, v/v/v), with AquaGro wetting agent (Aquatrols, Cherry Hill, NJ) at 0.2 $kg \cdot m^{-3}$, was used for media. Five experiments were conducted during different seasons (Table 6-1). The plants were grown with natural photoperiod extended to 16 h by 1000-W, high-pressure sodium lamps (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon

Table 6-1. Sowing schedule and initial media test (Hanlon et al., 1994) for Experiments 1 to 5.

Expt	Sowing date	Media test[z]						
		pH	EC ($dS \cdot m^{-1}$)	NO_3-N	P	K	Ca	Mg
				($mg \cdot kg^{-1}$)				
1	18 Jun 1994	5.1	0.1	0	1.0	16.6	1.3	4.0
2	23 Feb 1995	5.0	0.1	0	0.6	12.6	1.1	4.5
3	27 Jun 1995	4.8	0.1	0	0.5	13.1	1.2	4.3
4	18 Sep 1995	4.4	0.3	0	0.3	20.9	1.6	3.9
5	02 Apr 1996	4.5	0.2	0	0.4	23.0	0.8	9.9

[z]Concentrations in the saturated paste extract.

flux). A record of cloud cover was kept as an indication of the evaporative demand of the atmosphere. Greenhouse air temperature just above the plant canopy, and media temperatures were recorded by a Series 3020T Datalogger (Electronic Controls Design, Inc., Mulino, OR). The flats were seeded, then covered with a thin layer of vermiculite, overhead irrigated enough to moisten the vermiculite, and transferred to a cooler at 20 °C for germination. After 48 h, flats were returned to the greenhouse.

In Experiment 1, the effect of irrigation frequency on lettuce transplant growth was evaluated with four treatments, consisting of 0, 20, 40, and 60 % moisture deficit from field capacity (FC). Flats were weighed twice daily, and irrigation was performed when the flats had lost a predetermined amount of moisture. Irrigation was by means of floating flats directly in water or nutrient solution. All the treatments were fertigated seven times during the

duration of the trial. Fertilizers (in $mg \cdot L^{-1}$) consisted of 100 N, 30 P, 30 K, 100 Ca, and half-strength Hoagland's solution for micronutrients only (Hoagland and Arnon, 1950), that was comprised of Mg, S, B, Cu, Cl, Mo, and Zn. The experiment was a randomized complete-block design with 4 treatments and 4 replications.

Plants in Experiments 2, 3, and 4 were grown with N at 0, 30, 60, 90, or 120 $mg \cdot L^{-1}$. Other nutrients were applied at equivalent rates to all plants and consisted of (in $mg \cdot L^{-1}$) 30 P, 30 K, 30 Ca, and half-strength Hoagland's solution for micronutrients only (Hoagland and Arnon, 1950). Fertigation frequency treatments were sub-irrigated daily, or sub-irrigated every second, third, or fourth day. The experiments were arranged in a randomized complete-block design with 20 treatments consisting of a factorial combination of 5 levels of N and 4 levels of fertigation frequency in 4 replications.

Plants in Experiment 5 were grown with N at 0 or 60 $mg \cdot L^{-1}$ applied at four different times using sub-irrigation. The first 60 $mg \cdot L^{-1}$ N was applied every other day for the first 14 days, then no further N was applied. The second N treatment was applied every other day only during the last 14 days of a 28-day growing period. The third N treatment was applied every fourth day, while the fourth N treatment was applied every other day for a 28-day growing period.

Other nutrients were supplied every other day as described for Experiment 2. The experiment was a randomized complete-block design with 5 treatments and 4 replications.

Plant samples, 5 per treatment, were taken at 13, 21, and 28 days after sowing (DAS) for growth measurements. Measurements included shoot and root fresh and dry mass, and leaf area (measured by a LI-3100 leaf area meter; LI-COR, Lincoln, NE). Growth variables calculated were: root:shoot ratio (RSR = dry root mass ÷ dry shoot mass), relative growth rate (RGR = [ln (final total dry mass) - ln (initial total dry mass) ÷ (final time - initial time)]), net assimilation rate (NAR = [(final total dry mass - initial total dry mass) ÷ (final time - initial time) × {(ln (final leaf area) - ln (initial leaf area)} ÷ (final leaf area - initial leaf area)]), specific leaf area (SLA = leaf area ÷ dry shoot mass), leaf area ratio (LAR = leaf area ÷ total dry mass), leaf mass ratio (LMR = dry shoot mass ÷ total dry mass), and root mass ratio (RMR = dry root mass ÷ total dry mass) (Hunt, 1978; 1982; Dubik et al., 1992).

At the last sampling date in Experiment 5, fresh roots were scanned with a Hewlett Packard desktop scanner and analyzed with MacRHIZO software (Regent Instruments Inc., Quebec, Canada) at 300 dpi for length, area, and diameter. Additionally, pull force, the force required to pull a lettuce transplant out of a flat using Model DPP Dial Push-

Pull Gauge (John Chatillon and Sons, Kew Gardens, NY) attached to a binder clip, was measured. Pulling success was calculated as the percentage of 5 plants per treatment that could be pulled from the transplant flat without any breakage.

Leaf petioles were collected 28 DAS in Experiment 5, for sap testing. The sap was squeezed from collected petiole pieces using a hydraulic sap press onto sampling sheets according to Hochmuth (1992). A CARDY meter (Spectrum Technologies, Inc., Plainfield, IL) was used to measure NO_3-N concentrations in the petiole sap.

Dry shoot samples from the last sampling dates were ground to pass a 20-mesh screen and dry-ashed for P and K in Experiment 1 or acid-digested for total Kjeldahl N in all experiments according to Wolf (1982). For total P and K determination, 0.5 g subsamples were weighed into 10 mL beakers. The samples were then dry-ashed in a muffle furnance at 500 °C for 10 h. The ash was moistened with 1 N HCl and poured into 50 mL volumetric flasks, and brought to volume with 1 N HCl. The solutions were filtered through 'Q8' filter paper (Fisher brand), with a particle retention of > 10 μm, into 25 mL scintillation vials. The solution samples were sent to the Analytical Research Laboratory, University of Florida, and analyzed with Model 61-E

Inductively Coupled Plasma Spectrometry (Thermo Jarrell Ash Corporation, Franklin, MA).

For total Kjeldahl N, 0.25 g subsamples were weighed into 50 mL digestion tubes. Sulfuric acid and 30 % hydrogen peroxide were added to the tubes which were then heated on a digestion block at 375 °C. After the digestion process was completed (a total of 2.5 h), the samples were allowed to cool, and deionized water was used to bring the volume to 25 mL. The solutions were filtered through 'P8' filter papers (Fisher brand), with a particle retention of > 25 μm into 25 mL scintillation vials. The solution samples were then sent to the Analytical Research Laboratory, University of Florida, and N was determined on a 300 Series Rapid Flow Analyzer (ALPKEM Corporation, Wilsonville, OR).

Data were subjected to analysis of variance using the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Treatment sums of squares were partitioned into linear or quadratic polynomial contrasts for Experiment 1. Data in Experiments 2, 3, and 4 were subjected to regression analysis. Bonferroni multiple comparison procedure (Neter et al., 1990) was used for multiple pairwise comparisons of treatment means.

Field Experiments

Plants from each treatment in Experiments 2 and 4 were transplanted into an Arredondo fine sandy soil (loamy, siliceous, hyperthermic Grosarenic Paleudults) in beds covered with white-on-black polyethylene-mulch (0.038 mm thick) at the University of Florida Horticultural Unit, Gainesville (Table 6-2). The experiments were arranged in a

Table 6-2. Transplanting schedule and initial soil test (Hanlon et al., 1994) for Experiments 1 and 2.

Experiment	Transplanting date	Soil test[z]					
		pH	EC	P	K	Ca	Mg
			($dS \cdot m^{-1}$)	($mg \cdot kg^{-1}$)			
1	23 Mar 1995	6.3	0.1	208	46	452	45
2	17 Oct 1995	5.9	0.1	185	30	733	54

[z]pH and EC determined on 2:1 water to soil ratio procedure, while elements are from a Mehlich-1 extractant.

randomized complete-block design with 20 treatments consisting of a factorial combination of 5 levels of N and 4 levels of fertigation frequency in 4 replications. Preplant fertilizer (13N-0P-10.8K) was applied broadcast and incorporated in the bed at 230 $kg \cdot ha^{-1}$. Raised beds spaced 1.2 m center to center, were fumigated with methyl bromide and then covered with the polyethylene mulch. There were 30 plants per plot planted on double offset rows with a spacing of 0.3 m between plants and between rows on the bed (equivalent to 54,000 plants/ha).

Just after transplanting, 100 mL of nutrient solution (150 $mg \cdot L^{-1}$ 20N-8.6P-16.7K) was applied to each transplant hole as a starter fertilizer. Water was applied twice daily for 20 min each cycle, using drip irrigation lines placed on the center of the bed with emitters spaced 0.3 m apart. Tensiometers (Irrometer Company, Inc., Riverside, CA) were used to monitor soil moisture adequacy in the beds. The root zone area was maintained at approximately -10 kPa according to Hochmuth and Clark (1991). Starting one week after transplanting, fertilizer at a rate of 15 $kg \cdot ha^{-1}$ N and 16 $kg \cdot ha^{-1}$ K, supplied from NH_4NO_3 and KNO_3, was injected weekly using a venturi pump (Netafim Irrigation, Altamonte Springs, FL), with the last application one week before harvest to give a total amount of 150 $kg \cdot ha^{-1}$ N and 180 $kg \cdot ha^{-1}$ K. Cultural management practices were similar to those used commercially in Florida (Hochmuth et al., 1988).

At head maturity, the center 20 plants in a plot were cut, weighed individually, and then 10 heads were assessed for firmness, cut longitudinally for height, diameter, stem width, and core length measurements. Wrapper leaves were sampled at harvest for analysis of tissue N according to Wolf (1982) as described for Greenhouse Experiments. Field data were subjected to regression analysis using the Statistical Analysis System (SAS Institute, Inc., Cary, NC).

Results and Discussion

Greenhouse Experiments

Experiment 1 was conducted to assess the effect of water deficit on lettuce growth. Greenhouse temperatures ranged from 19 to 39 °C (Fig. 6-1). The average daily maximum media temperature was 32 °C, while the average daily minimum media temperature was 20 °C. During the course of the trial, there were 19 sunny and 9 cloudy days with rain during three of the cloudy days.

For plants sampled 15, 22, and 29 days after sowing (DAS), fresh and dry shoot mass responded in quadratic fashion to irrigation frequency (Table 6-3). Fresh and dry shoot mass were least at the 0 % level of moisture deficit from field capacity (FC = 368 %, m/m) and greatest at the 40 % level for plants grown to 15 DAS. However, dry shoot mass was least at the 60 % level of moisture deficit by this sampling date. For plants sampled 22 DAS, fresh and dry shoot mass were least at the 0 % level of moisture deficit from FC, and greatest at the 40 % level, with no further increases at higher moisture deficits. For plants sampled 29 DAS, fresh and dry shoot mass were increased by increasing moisture deficit from 0 to 60 % below FC.

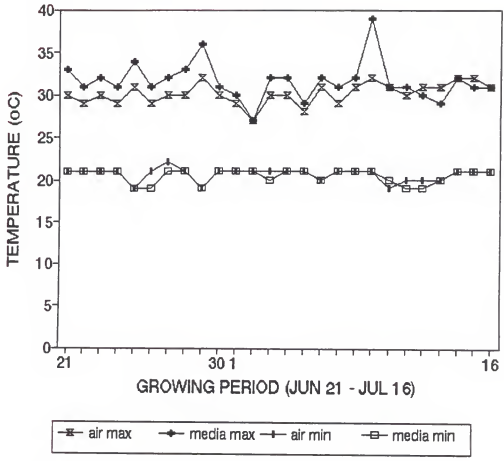


Fig. 6-1. Maximum and minimum air and media temperature during transplant production for Experiment 1, Jun/Jul 1994.

Table 6-3. Root and shoot characteristics of lettuce transplants as affected by irrigation frequency for Experiment 1, June/July 1994.

Moisture deficit from FC (%)	Approximate irrigation frequency (days)	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)	Leaf tissue P ($g \cdot kg^{-1}$)	Leaf tissue K ($g \cdot kg^{-1}$)
				15 Days After Sowing					
0	1	145	10.8	75	4.7	5.4			
20	2	209	11.0	82	4.6	8.1			
40	2-3	211	11.7	96	5.3	8.3			
60	3-4	170	7.4	45	2.9	6.5			
Response		Q**	Q**	Q**	Q**	Q**			
				22 Days After Sowing					
0	1	302	24.5	136	11.3	10.5			
20	2	577	38.3	173	12.1	20.6			
40	2-3	646	39.7	192	12.4	23.0			
60	3-4	647	35.6	188	11.6	23.9			
Response		Q**	Q**	Q*	NS	Q**			
				29 Days After Sowing					
0	1	635	49.9	239	21.0	21.5	17.6	2.7	33.7
20	2	979	69.9	292	23.9	34.4	18.2	2.9	37.7
40	2-3	1274	73.8	305	20.0	41.8	22.6	3.7	44.2
60	3-4	1475	84.8	335	22.8	50.4	26.9	4.1	47.4
Response		Q**	Q**	L*	NS	Q**	Q**	L**	L**

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

For plants sampled 15 and 22 DAS, fresh root mass responded in quadratic fashion to irrigation frequency. For plants sampled 29 DAS, fresh root mass increased linearly in response to moisture deficit from FC. For plants sampled 15 DAS, dry root mass responded in quadratic fashion to irrigation frequency, but irrigation frequency did not affect dry root mass for plants sampled 22 and 29 DAS.

Leaf area responded in quadratic fashion to irrigation frequency, regardless of sampling date (Table 6-3). For plants sampled 15 DAS, leaf area was least at the 0 % level of moisture deficit from FC, and greatest at the 40 % moisture deficit. For plants sampled 22 and 29 DAS, leaf area was increased by increasing the moisture deficit from 0 to 60 % below FC.

For plants sampled 29 DAS, leaf tissue N increased in quadratic fashion, while leaf tissue P and K increased linearly in response to increasing the moisture deficit from 0 to 60 % below FC. Lower levels of tissue N, P, and K in transplants which were irrigated more frequently compared with those which were irrigated less frequently, indicated that some nutrient leaching might have occurred with frequent irrigations. Therefore, further investigations were needed to determine optimum fertigation frequency rather than irrigation frequency, due to the potential leaching problem.

For plants sampled 15 DAS, RSR was not influenced by increasing moisture deficit from FC (Table 6-4). For plants sampled 22 and 29 DAS, RSR decreased quadratically as moisture deficit increased. For plants sampled 22 DAS, RSR was greatest at the 0 % level of moisture deficit. For plants sampled 29 DAS, RSR was decreased by increasing moisture deficit from 0 to 40 %, and thereafter there was no further decrease in RSR.

For plants grown to 22 DAS, RGR increased linearly in response to irrigation frequency, while for plants grown to 29 DAS, RGR increased in quadratic fashion in response to irrigation frequency. Relative growth rate values were lower by 29 DAS compared to 22 DAS. Irrigation frequency did not influence NAR for plants grown to 22 DAS, but NAR decreased in quadratic fashion in response to irrigation frequency for plants grown to 29 DAS. For plants sampled 15, 22, and 29 DAS, both SLA and LAR increased linearly in response to irrigation frequency. Specific leaf area and LAR were least at the 0 % level of moisture deficit from FC, and greatest at the 60 % level of moisture deficit.

For plants sampled 15 DAS, irrigation frequency did not influence LMR or RMR. For plants sampled 22 and 29 DAS, LMR increased in quadratic fashion, while RMR decreased in quadratic fashion in response to irrigation frequency. Leaf mass ratio was least at the 0 % level of moisture deficit

Table 6-4. Influence of irrigation frequency on growth characteristics of lettuce transplants for Experiment 1, June/July 1994.

Moisture deficit from FC (%)	Approximate irrigation frequency (days)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			15 Days After Sowing					
0	1	0.44			0.51	0.35	0.70	0.30
20	2	0.42			0.74	0.52	0.70	0.30
40	2-3	0.46			0.71	0.49	0.69	0.31
60	3-4	0.40			0.90	0.64	0.72	0.28
Response		NS			L**	L**	NS	NS
			22 Days After Sowing					
0	1	0.46	0.84	2.64	0.43	0.29	0.68	0.32
20	2	0.32	1.17	2.59	0.54	0.41	0.76	0.24
40	2-3	0.31	1.12	2.43	0.58	0.44	0.76	0.24
60	3-4	0.32	1.53	2.76	0.67	0.51	0.76	0.24
Response		Q**	L**	NS	L**	L**	Q**	Q**
			29 Days After Sowing					
0	1	0.42	0.68	2.29	0.43	0.30	0.70	0.30
20	2	0.34	0.62	1.62	0.49	0.37	0.75	0.25
40	2-3	0.27	0.59	1.33	0.57	0.45	0.79	0.21
60	3-4	0.27	0.83	1.70	0.59	0.47	0.79	0.21
Response		Q**	Q**	Q**	L**	L**	Q*	Q*

Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

from FC, and greatest at the 20 % level of moisture deficit by 22 DAS, with no further increases in LMR at higher levels. The opposite response occurred for RMR. For plants sampled 29 DAS, LMR was increased by increasing moisture deficit from 0 to 40 % below FC, with no further increases in LMR at higher levels. The opposite response occurred for RMR.

It was observed that transplants kept close to field capacity (FC) and those which were irrigated at 60 % moisture deficit from FC were inferior because they could not be easily pulled from the transplant flat compared with those irrigated at 20 or 40 % moisture deficit from FC. Roots of transplants which were irrigated less frequently were observed as being finer and they penetrated the sides of cells, apparently causing root systems not to pull out completely from the transplant flat.

In experiment 1, optimum irrigation frequency for lettuce transplants was investigated independent of the amount of fertilizer applied. Leaf tissue analysis indicated that frequent irrigations may have resulted in leaching of fertilizer nutrients. The next three experiments, therefore, were conducted to determine optimum fertigation frequency, by investigating simultaneously both the nutrition and the water requirements of the transplants. Since the lettuce transplants could not be easily pulled from the transplant

flat and total potential growth due to N additions was not achieved after 28 days by growing plants with 60 $mg \cdot L^{-1}$ N (Chapter 5), N was increased to 120 $mg \cdot L^{-1}$ in experiments which follow.

Experiment 2 was conducted during the spring in order to determine the effects of N fertigation frequency on lettuce growth. Greenhouse temperatures ranged from 13 to 46 °C (Fig. 6-2). The average daily maximum media temperature was 32 °C, while the average daily minimum media temperature was 20 °C. During the course of the trial, there were totals of 18 sunny and 8 cloudy days, with rain during four of the cloudy days.

Since dry root mass was maximized with 60 $mg \cdot L^{-1}$ in Experiment 2, this N level was used for comparison whenever there were interactions between fertilizer N and fertigation frequency.

For plants sampled 13 DAS (Fig. 6-3), 21 DAS (Fig. 6-4) and 28 DAS (Fig. 6-5), dry shoot mass increased in quadratic fashion to applied N when fertigation frequency was daily, every second or every third day. Dry shoot mass increased linearly in response to applied N when fertigation frequency was every fourth day. For plants sampled 13 DAS, fertigating every third day was as adequate as daily fertigation for increased shoot growth. However, for plants sampled 21 and

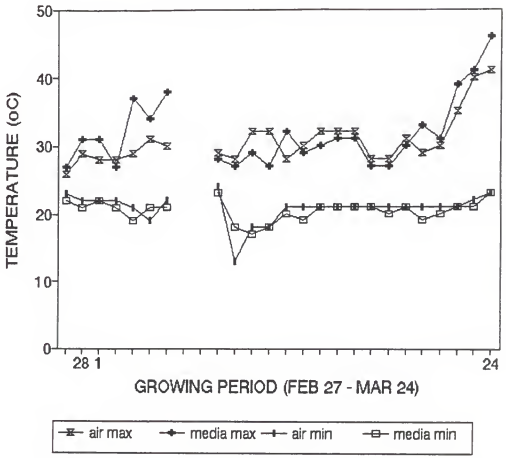
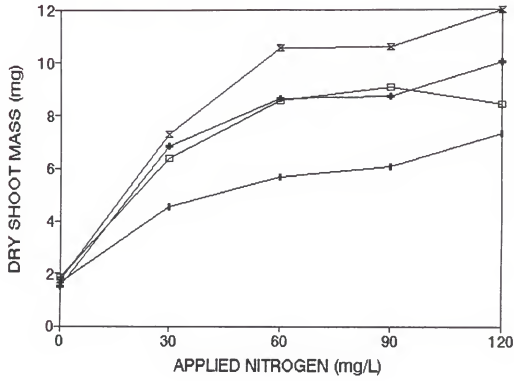


Fig. 6-2. Maximum and minimum air and media temperature during transplant production for Experiment 2, Feb/Mar 1995.

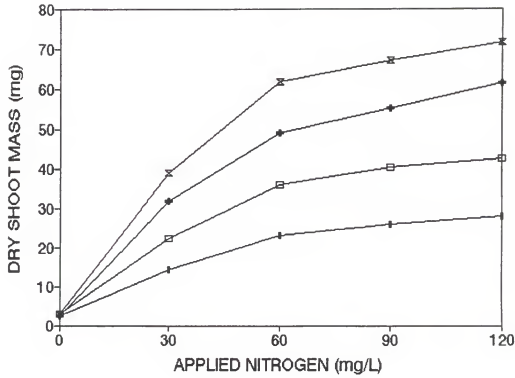


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	5.6	8.6	8.6	10.5

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-3. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 13 days after sowing for Experiment 2, Feb/Mar 1995.

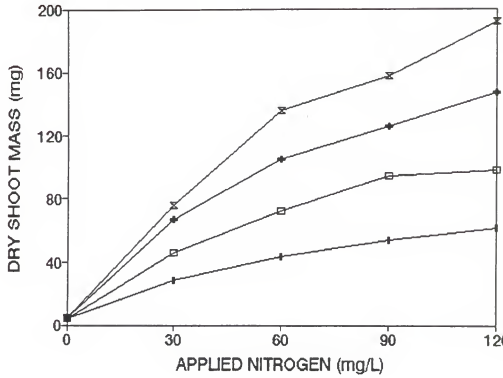


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	23.0	35.7	48.9	61.6

All means are significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-4. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 21 days after sowing for Experiment 2, Feb/Mar 1995.



N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	43.1	72.0	104.8	135.6

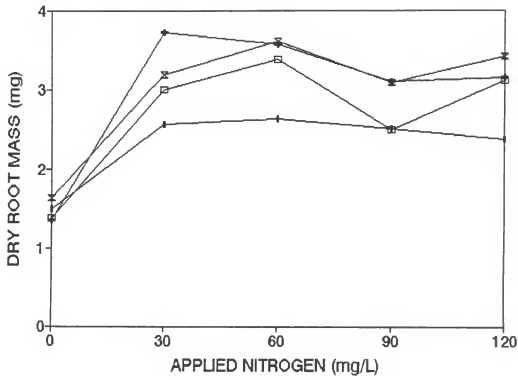
All means are significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-5. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 28 days after sowing for Experiment 2, Feb/Mar 1995.

28 DAS, dry shoot mass was increased by each level of fertigation frequency.

For plants sampled 13 DAS, dry root mass responded in quadratic fashion to applied N at all fertigation frequencies, except when fertigating every fourth day wherein N did not affect dry root mass (Fig. 6-6). The greatest increases in dry root mass to applied N occurred between 0 and 30 $mg \cdot L^{-1}$, when transplants were fertigated every day, every second day or every third day. For plants sampled 21 DAS (Fig. 6-7) and 28 DAS (Fig. 6-8), dry root mass increased in quadratic fashion in response to applied N, regardless of fertigation frequency. For plants sampled 21 DAS, dry root mass was least when fertigation frequency was every fourth day. For plants sampled 28 DAS, the optimum N to maximize dry root mass was 60 $mg \cdot L^{-1}$, regardless of fertigation frequency. Fertigating every other day was as effective as daily fertigation for increasing root growth.

For plants sampled 13 DAS (Fig. 6-9), leaf area increased in quadratic fashion to applied N, regardless of fertigation frequency. For plants sampled 22 DAS (Fig. 6-10), leaf area increased in quadratic fashion to applied N only when the fertigation frequency was daily to every third day, but increased linearly when the fertigation frequency was every fourth day. For plants sampled 28 DAS (Fig. 6-11),

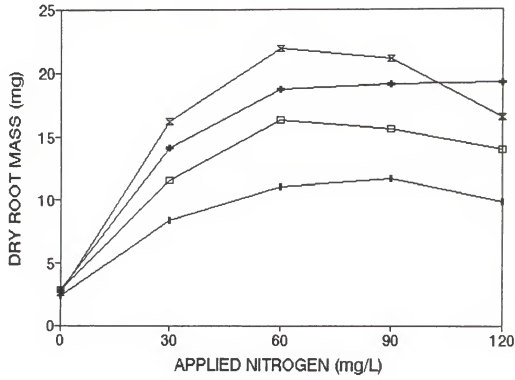


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	2.6	3.4	3.6	3.6

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-6. Lettuce transplant dry root mass response to N nutrition and fertigation frequency 13 days after sowing for Experiment 2, Feb/Mar 1995.

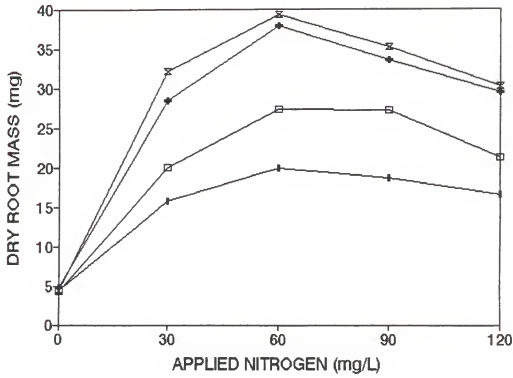


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	11.0	16.3	18.7	21.9

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-7. Lettuce transplant dry root mass response to N nutrition and fertigation frequency 21 days after sowing for Experiment 2, Feb/Mar 1995.

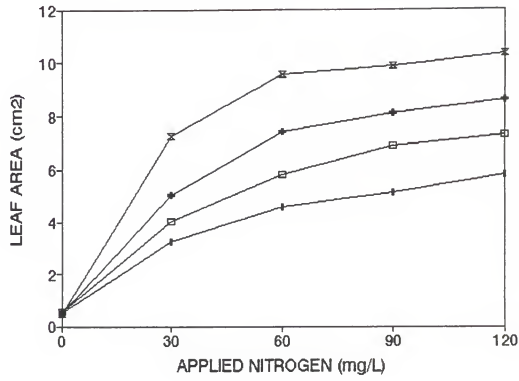


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	19.8	27.2	37.9	39.2

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-8. Lettuce transplant dry root mass response to N nutrition and fertigation frequency 28 days after sowing for Experiment 2, Feb/Mar 1995.

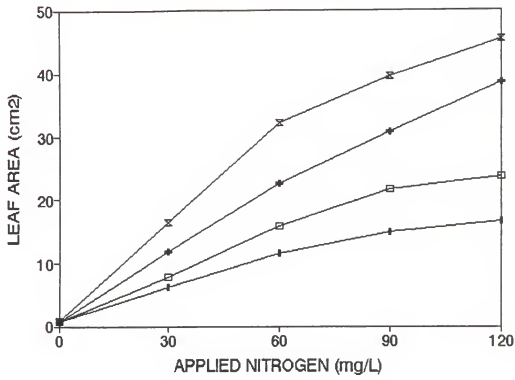


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	4.5	5.8	7.4	9.6

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-9. Lettuce transplant leaf area response to N nutrition and fertigation frequency 13 days after sowing for Experiment 2, Feb/Mar 1995.

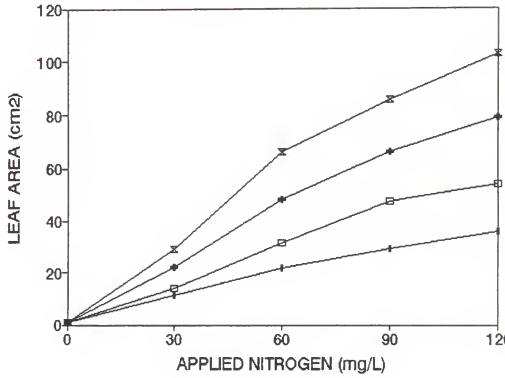


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	11.5	15.7	22.5	32.1

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-10. Lettuce transplant leaf area response to N nutrition and fertigation frequency 21 days after sowing for Experiment 2, Feb/Mar 1995.



N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	21.9	31.5	47.9	65.9

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

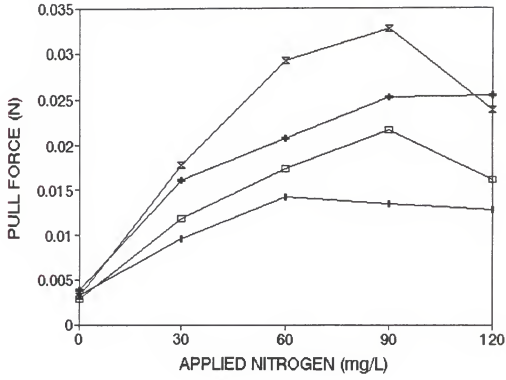
Fig. 6-11. Lettuce transplant leaf area response to N nutrition and fertigation frequency 28 days after sowing for Experiment 2, Feb/Mar 1995.

leaf area increased in quadratic fashion to applied N when the fertigation frequency was daily or every second day, but increased linearly when the fertigation frequency was every third or fourth day. Leaf area was greatest when fertigation was daily and least when fertigation was every third or fourth day, regardless of sampling date.

For plants sampled 28 DAS, the force required to pull transplants from the transplant flat increased in quadratic fashion to applied N (Fig. 6-12). The greatest force was required to pull transplants produced with daily fertigation of 90 $mg \cdot L^{-1}$ N. There were no N by fertigation frequency interactions for pulling success (Table 6-5). Pulling success increased in quadratic fashion to applied N. Pulling success was improved dramatically from 16 to 95 % when N was increased from 0 to 60 $mg \cdot L^{-1}$. Low pull force was associated with low pulling success due to plants breaking when pulled. With added N, the stems and roots were strong enough to prevent breakage.

For plants sampled 28 DAS, leaf tissue N increased linearly in response to applied N (Fig. 6-13). Leaf tissue N was increased from about 5 to 40 $g \cdot kg^{-1}$ by applied N, regardless of fertigation frequency. Fertigation frequency did not influence N concentration in transplant leaves.

There were no N by fertigation frequency interactions for RSR and RGR (Table 6-5). For plants sampled 13, 21, and



N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	0.014	0.017	0.021	0.029

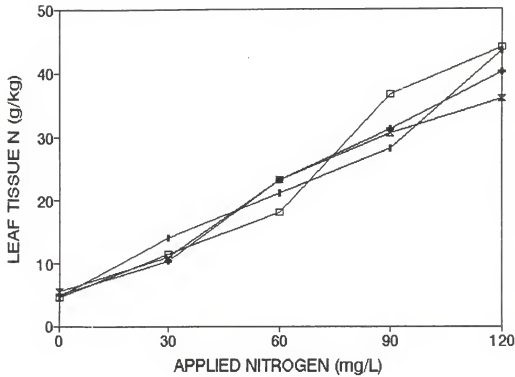
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-12. Lettuce transplant pull force response to N nutrition and fertigation frequency 28 days after sowing for Experiment 2, Feb/Mar 1995.

Table 6-5. Root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 2, February/March 1995.

Treatment[z]	Pulling success (%)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)
		13 Days After Sowing	
N ($mg \cdot L^{-1}$)			
0		0.88	
30		0.52	
60		0.41	
90		0.34	
120		0.33	
Response		Q**	
F (days)			
1		0.48	
2		0.51	
3		0.46	
4		0.54	
Response		NS	
N × F		NS	
		21 Days After Sowing	
Nitrogen ($mg \cdot L^{-1}$)			
0		1.03	0.54
30		0.50	1.40
60		0.43	1.59
90		0.38	1.69
120		0.31	1.62
Response		Q**	Q**
F (days)			
1		0.45	1.51
2		0.53	1.50
3		0.55	1.30
4		0.59	0.16
Response		L*	L**
N × F		NS	NS
		28 Days After Sowing	
Nitrogen ($mg \cdot L^{-1}$)			
0	16	1.01	0.51
30	86	0.47	0.68
60	95	0.38	0.69
90	94	0.29	0.74
120	85	0.21	0.79
Response	Q**	Q**	L**
F (days)			
1	74	0.41	0.72
2	83	0.46	0.72
3	79	0.47	0.65
4	65	0.55	0.65
Response	Q**	L**	L*
N × F	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).



N at 60 mg·L⁻¹

Fertigation frequency	3	4	2	1
Treatment means	1.80	2.11	2.31	2.32

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-13. Lettuce transplant leaf tissue N response to N nutrition and fertigation frequency 28 days after sowing for Experiment 2, Feb/Mar 1995.

28 DAS, RSR values decreased in quadratic fashion when N was applied. For plants sampled 13 DAS, fertigation frequency did not influence RSR values, but for plants sampled 21 and 28 DAS, RSR values increased linearly when the period between each fertigation was increased.

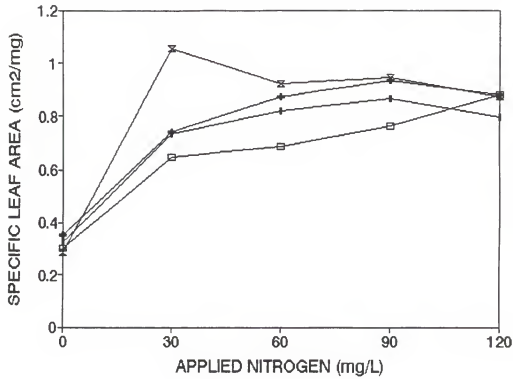
For plants grown to 21 DAS, RGR increased in quadratic fashion to applied N, while for plants grown to 28 DAS, RGR increased linearly in response to applied N (Table 6-5). Larger values of RGR by 21 DAS compared to 28 DAS, indicated that younger transplants had greater efficiency for growth than older ones. However, RGR values decreased when the period between each fertigation was increased. There were no N by fertigation frequency interactions for NAR (Table 6-6). For plants grown to 21 or 28 DAS, NAR decreased in quadratic fashion to applied N. Net assimilation rate responded in quadratic fashion to fertigation frequency for plants grown to 21 DAS, but for plants grown to 28 DAS, fertigation frequency did not influence NAR.

For plants sampled 13 DAS, SLA (Fig. 6-14) and LAR (Fig. 6-15) increased in quadratic fashion in response to applied N, regardless of fertigation frequency. The greatest increases in SLA or LAR to applied N were between 0 and 30 $mg \cdot L^{-1}$. Fertigating every day was better than fertigating every third day in increasing SLA or LAR. For plants sampled 21 and 28 DAS, there were no N by fertigation frequency

Table 6-6. Influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 2, Feb/Mar 1995.

Treatment[z]	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
		13 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0				0.54	0.46
30				0.66	0.34
60				0.71	0.29
90				0.75	0.25
120				0.76	0.24
Response				Q**	Q**
F (days)					
1				0.70	0.30
2				0.68	0.32
3				0.70	0.30
4				0.66	0.34
Response				NS	NS
N × F		*	**	NS	NS
		21 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	3.60	0.27	0.14		0.50
30	4.03	0.39	0.26		0.33
60	3.81	0.48	0.34		0.30
90	3.43	0.57	0.41		0.27
120	3.09	0.61	0.46		0.24
Response	Q**	Q**	Q**		Q**
F (days)					
1	3.54	0.49	0.36		0.29
2	3.97	0.46	0.32		0.32
3	3.79	0.43	0.29		0.34
4	3.07	0.49	0.32		0.36
Response	Q**	Q**	Q**		L**
N × F	NS	NS	NS	*	NS
		28 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	4.43	0.20	0.10	0.50	0.50
30	2.73	0.36	0.24	0.68	0.32
60	2.02	0.47	0.35	0.73	0.27
90	1.81	0.53	0.42	0.78	0.22
120	1.73	0.55	0.45	0.83	0.17
Response	Q**	Q**	Q**	Q**	Q**
F (days)					
1	2.41	0.43	0.33	0.74	0.26
2	2.76	0.41	0.31	0.71	0.29
3	2.53	0.40	0.30	0.70	0.30
4	2.47	0.45	0.31	0.67	0.33
Response	NS	Q**	Q**	L**	L**
N × F	NS	NS	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

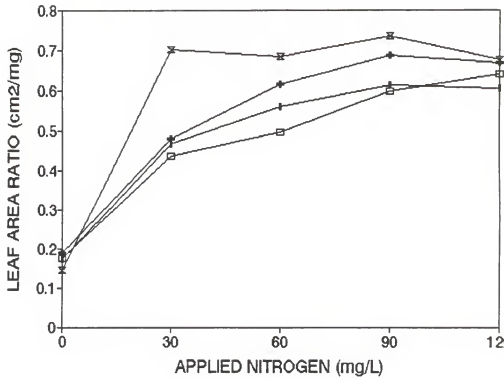


N at 60 mg·L^{-1}

Fertigation frequency	3	4	2	1
Treatment means	0.68	0.82	0.87	0.92

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-14. Lettuce transplant specific leaf area response to N nutrition and fertigation frequency 13 days after sowing for Experiment 2, Feb/Mar 1995.



N at 60 mg·L⁻¹

Fertigation frequency	3	4	2	1
Treatment means	0.49	0.56	0.61	0.68

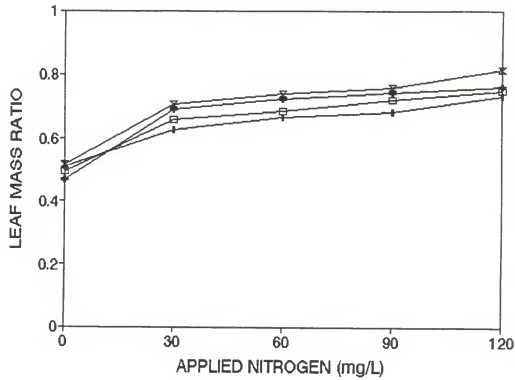
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-15. Lettuce transplant leaf area ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 2, Feb/Mar 1995.

interactions for SLA and LAR (Table 6-6). Both SLA and LAR increased in quadratic fashion in response to applied N. Fertigating every day or every fourth day increased SLA more than fertigating every second or third day. However, LAR was only increased by daily fertigation.

For plants sampled 13 and 28 DAS, there were no N by fertigation frequency interactions for LMR. Leaf mass ratio increased in quadratic fashion in response to applied N. Fertigation frequency did not influence LMR for plants sampled 13 DAS, but frequent fertigations increased LMR for plants sampled 28 DAS. For plants sampled 21 DAS (Fig. 6-16), LMR increased in quadratic fashion to applied N when the fertigation frequency was daily or every second or third day. When the fertigation frequency was every fourth day, LMR increased linearly in response to applied N. The greatest increases in LMR to applied N occurred between 0 and 30 $mg \cdot L^{-1}$, when transplants were fertigated every day, or every second and third day. Fertigation frequency did not influence LMR for plants sampled 21 DAS.

For plants sampled 13, 21, and 28 DAS, there were no N by fertigation frequency interactions for RMR (Table 6-6). Root mass ratios decreased in quadratic fashion when N was applied, regardless of sampling date. For plants sampled 13 DAS, RMR was not affected by fertigation frequency, but for



N at 60 mg·L^{-1}

Fertigation frequency	3	4	2	1
Treatment means	0.67	0.69	0.72	0.74

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-16. Lettuce transplant leaf mass ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 2, Feb/Mar 1995.

plants sampled 21 and 28 DAS, RMR was increased by less frequent fertigations.

Results of Experiment 2 indicated that, overall, high quality transplants could be produced with 60 $mg \cdot L^{-1}$ N, supplied every second day via floatation irrigation, especially when evaluating transplant quality based on dry root mass 28 DAS. Quality transplants had dry root mass of about 38 mg and dry shoot mass of about 100 mg, 28 DAS.

In order to further test this conclusion, Experiment 3 was conducted during the summer, instead of spring, under greenhouse temperatures ranging from 26 to 48 °C (Fig. 6-17). The average daily maximum media temperature was 38 °C, while the average daily minimum media temperature was 28 °C. During the course of the trial, there were totals of 22 sunny and 5 cloudy days, with rain during four of the cloudy days.

Since dry root mass was maximized with 30 $mg \cdot L^{-1}$ in Experiment 3, this N level was used for comparison whenever there were interactions between fertilizer N and fertigation frequency.

For plants sampled 13 DAS (Fig. 6-18) and 21 DAS (Fig. 6-19), dry shoot mass increased in quadratic fashion to applied N when the fertigation frequency was daily, every second day, or every third day. When the fertigation frequency was every fourth day, dry shoot mass increased

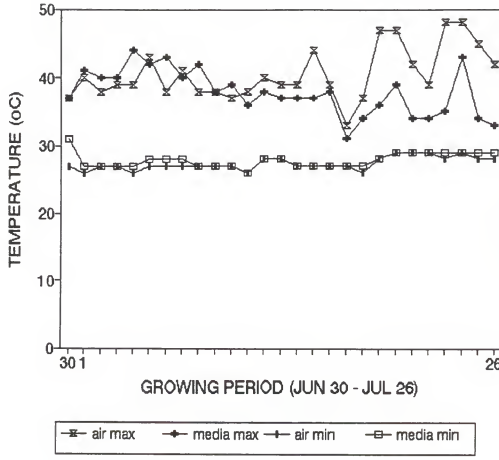
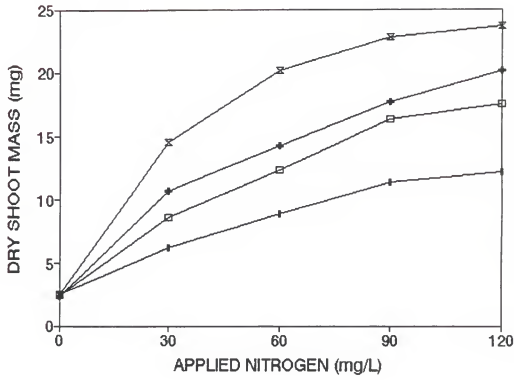


Fig. 6-17. Maximum and minimum air and media temperature during transplant production for Experiment 3, July 1995.

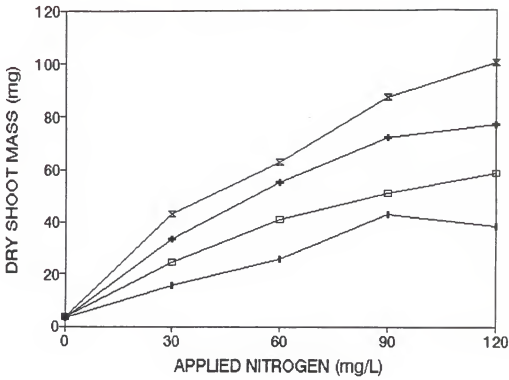


N at 30 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	6.2	8.6	10.7	14.5

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-18. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 13 days after sowing for Experiment 3, July 1995.



N at 30 mg·L⁻¹

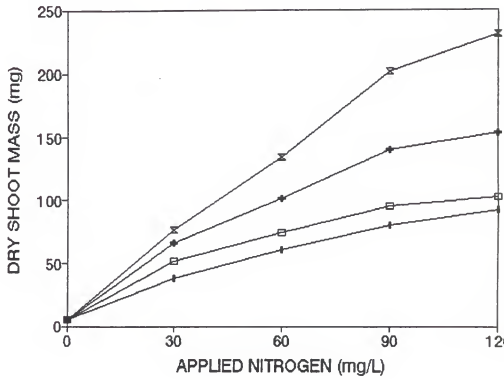
Fertigation frequency	4	3	2	1
Treatment means	15.4	24.2	33.3	43.0

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-19. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.

linearly in response to N. Daily fertigation, compared to other frequencies, increased dry shoot mass for plants sampled 13 DAS. For plants sampled 21 DAS, fertigating every other day was as effective as fertigating daily in order to increase shoot growth. For plants sampled 28 DAS, dry shoot mass increased in quadratic fashion in response to applied N, regardless of fertigation frequency (Fig. 6-20). Fertigating every third day was as effective as daily fertigation in order to increase shoot growth.

For plants sampled 13 and 28 DAS, there were no N by fertigation frequency interactions for dry root mass (Table 6-7). Dry root mass increased in quadratic fashion in response to applied N by both sampling dates. For plants sampled 28 DAS, increasing N application from 0 to 30 $mg \cdot L^{-1}$ dramatically increased dry root mass from about 5 to 28 mg, thereafter dry root mass decreased. Fertigation frequency did not influence dry root mass for plants sampled 13 DAS, but for plants sampled 28 DAS, frequent fertigations led to increased root growth. For plants sampled 21 DAS (Fig. 6-21), dry root mass increased in quadratic fashion to applied N when fertigation frequency was every day to every third day. When fertigation frequency was every fourth day, dry root mass increased linearly in response to N. The greatest increases in dry root mass to applied N occurred between 0



N at 30 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	37.9	51.4	65.9	76.2

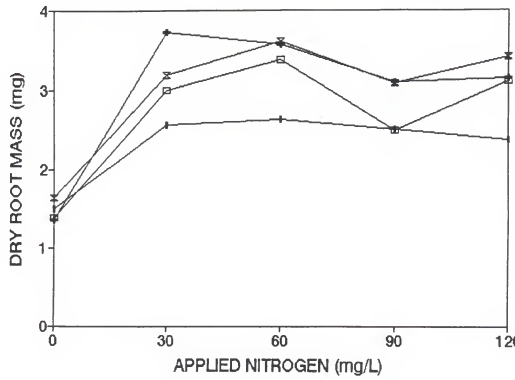
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-20. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 28 days after sowing for Experiment 3, July 1995.

Table 6-7. Root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 3, July 1995.

Treatment[z]	Dry root mass (mg)	Pull force (N)	Pulling success (%)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)
		13 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	2.1				
30	4.8				
60	4.9				
90	4.2				
120	4.1				
Response	Q**				
F (days)					
1	4.1				
2	4.5				
3	3.9				
4	3.5				
Response	NS				
N × F	NS			**	
		21 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0					0.41
30					1.04
60					1.17
90					1.26
120					1.26
					Q**
F (days)					
1					1.09
2					1.11
3					1.00
4					0.80
Response					L**
N × F	**			**	NS
		28 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	4.8	0.006	3	1.01	
30	28.4	0.022	73	0.50	
60	26.4	0.026	65	0.30	
90	25.7	0.029	69	0.18	
120	19.2	0.027	43	0.13	
Response	Q**	Q**	Q**	Q**	
F (days)					
1	25.1	0.025	45	0.41	
2	23.2	0.024	50	0.43	
3	17.6	0.019	55	0.49	
4	14.2	0.016	49	0.53	
Response	L**	L**	NS	NS	
N × F	NS	NS	NS	NS	**

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).



N at 30 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	8.0	12.8	16.0	19.8

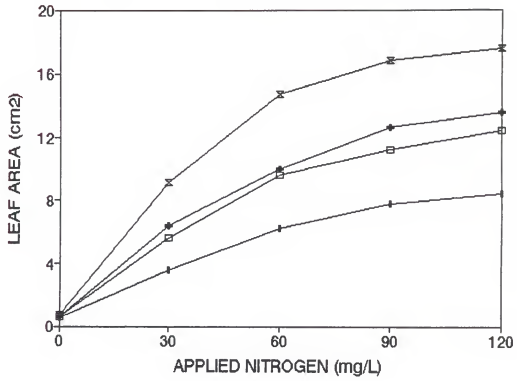
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-21. Lettuce transplant dry root mass response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.

and 30 $mg \cdot L^{-1}$, when transplants were fertigated every day, every second day, or every third day.

For plants sampled 13 DAS (Fig. 6-22), 21 DAS (Fig. 6-23), and 28 DAS (Fig. 6-24), leaf area increased in quadratic fashion in response to applied N, regardless of fertigation frequency. The exception was plants sampled 21 DAS wherein leaf area increased linearly in response to N when fertigation was every fourth day. For plants sampled 13 DAS, leaf area was increased by daily fertigation, while for plants sampled 21 and 28 DAS, fertigating every other day was as adequate as daily fertigation in order to achieve greater leaf area.

For plants grown to 28 DAS, there were no N by fertigation frequency interactions for pull force and pulling success (Table 6-7). Once again, the amount of force required to pull transplants from the transplant flat as well as pulling success increased in quadratic fashion in response to applied N. Approximately 73 % of transplants could be successfully pulled from the transplant flat when 30 $mg \cdot L^{-1}$ N was applied, compared to only 3 % with 0 N and 43 % with 120 $mg \cdot L^{-1}$ N. Low pull force was associated with low pulling success due to root systems breaking when pulled, especially with 0 N.

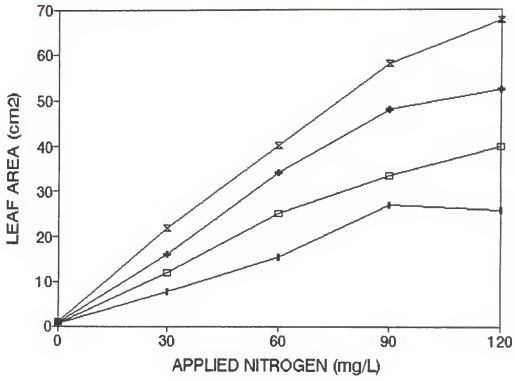


N at 30 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	3.6	5.6	6.4	9.1

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-22. Lettuce transplant leaf area response to N nutrition and fertigation frequency 13 days after sowing for Experiment 3, July 1995.

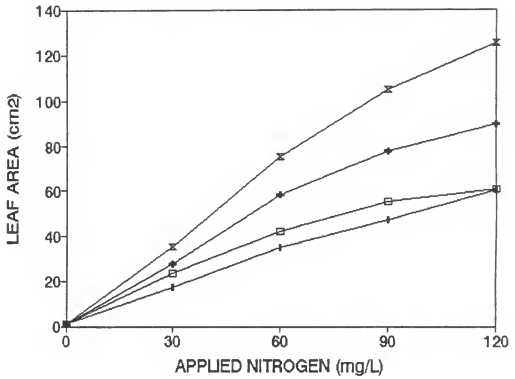


N at 30 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	7.7	11.9	16.1	21.9

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-23. Lettuce transplant leaf area response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.



N at 30 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	17.0	23.3	27.6	35.1

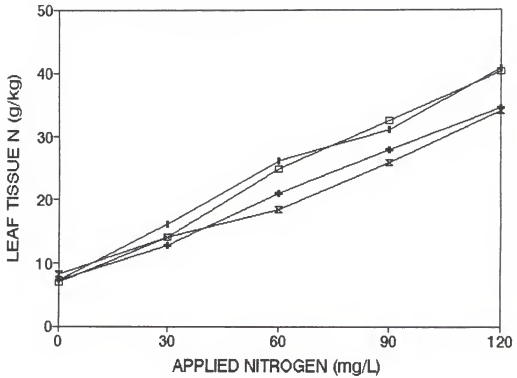
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-24. Lettuce transplant leaf area response to N nutrition and fertigation frequency 28 days after sowing for Experiment 3, July 1995.

For plants sampled 28 DAS (Fig. 6-25), leaf tissue N increased linearly in response to applied N, regardless of fertigation frequency. Fertigation frequency did not influence N concentrations in transplant leaves.

For plants sampled 13 DAS (Fig. 6-26), RSR values decreased in quadratic fashion to applied N when the fertigation frequency was every day to every three days. When the fertigation frequency was every fourth day, RSR values decreased linearly in response to N. Fertigating every fourth day increased RSRs compared to daily fertigation. For plants sampled 21 DAS (Fig. 6-27), RSR values decreased in quadratic fashion in response to applied N, regardless of fertigation frequency. For plants sampled 28 DAS, there were no N by fertigation frequency interactions for RSRs (Table 6-7). Fertigation frequency did not influence RSR values, but RSR values decreased in quadratic fashion in response to applied N.

For plants grown to 21 DAS, there were no N by fertigation frequency interactions for RGR. Relative growth rate increased in quadratic fashion to applied N, but decreased linearly in response to a decrease in fertigation frequency. For plants grown to 28 DAS (Fig. 6-28), RGR increased linearly in response to applied N when fertigation frequency was daily, but when fertigation frequency was every two to every three days, RGR increased in quadratic

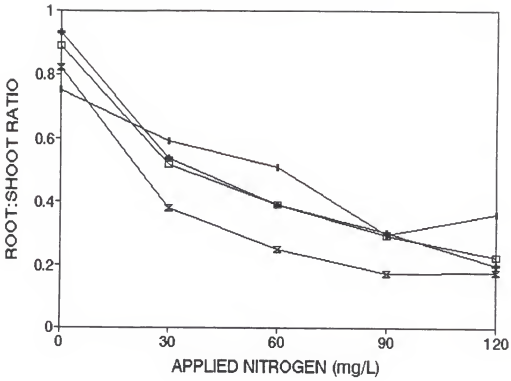


N at 30 mg·L^{-1}

Fertigation frequency	3	4	2	1
Treatment means	1.26	1.40	1.41	1.60

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-25. Lettuce transplant leaf tissue N response to N nutrition and fertigation frequency 28 days after sowing for Experiment 3, July 1995.

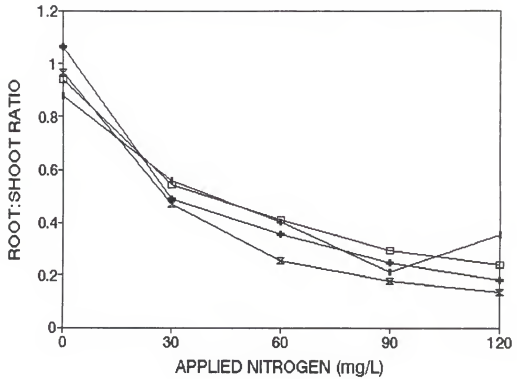


N at 30 mg·L⁻¹

Fertigation frequency	1	3	2	4
Treatment means	0.38	0.52	0.54	0.59

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-26. Lettuce transplant root:shoot ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 3, July 1995.

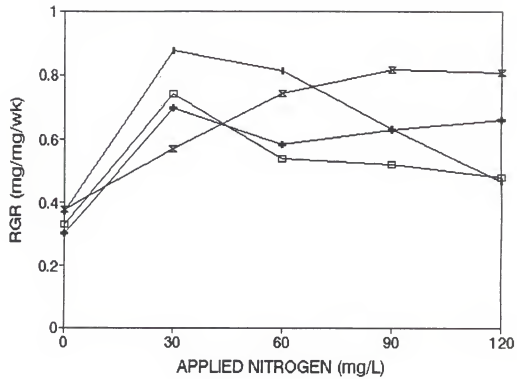


N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treatment means	0.47	0.49	0.54	0.56

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-27. Lettuce transplant root:shoot ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.



N at 30 mg·L^{-1}

Fertigation frequency	1	3	2	4
Treatment means	0.57	0.70	0.74	0.88

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-28. Lettuce transplant relative growth rate response to N nutrition and fertigation frequency 28 days after sowing for Experiment 3, July 1995.

fashion to N. The greatest increases in RGR in response to applied N occurred between 0 and 30 $mg \cdot L^{-1}$, when transplants were fertigated every second, third or fourth day. Fertigating every fourth day increased RGR values more than daily fertigation.

For plants grown to 21 and 28 DAS, there were no N by fertigation frequency interactions for NAR (Table 6-8). Net assimilation rate decreased in quadratic fashion in response to applied N. For plants grown to 21 DAS, NAR responded in quadratic fashion to fertigation frequency, but fertigation frequency did not influence NAR values for plants grown to 28 DAS. Although NAR was greatest with 0 N regardless of sampling date, the total production of dry matter over the same period was greater with any level of N.

For plants sampled 13, 21, and 28 DAS, there were no N by fertigation frequency interactions for SLA. Specific leaf area increased in quadratic fashion in response to applied N, regardless of sampling date. Fertigation frequency did not influence SLA. For plants sampled 13 and 28 DAS, there were no N by fertigation frequency interactions for LAR. For plants sampled 13 DAS, LAR increased in quadratic fashion in response to applied N, but decreased as the interval between each fertigation was delayed by one day. For plants sampled 28 DAS, LAR increased in quadratic fashion in response to applied N. Fertigation frequency, however, did not influence

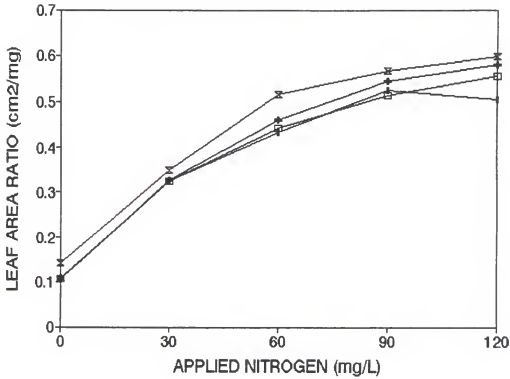
Table 6-8. Influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 3, July 1995.

Treatment[z]	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
		13 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0		0.25	0.14		
30		0.62	0.41		
60		0.74	0.54		
90		0.70	0.56		
120		0.70	0.57		
Response		Q**	Q**		
F (days)					
1		0.62	0.49		
2		0.59	0.43		
3		0.62	0.45		
4		0.58	0.40		
Response		NS	L*		
N × F		NS	NS	**	**
		21 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	3.27	0.23			
30	2.87	0.50			
60	2.40	0.62			
90	2.29	0.66			
120	2.20	0.68			
Response	Q*	Q**			
F (days)					
1	2.54	0.55			
2	2.86	0.54			
3	2.61	0.53			
4	2.45	0.48			
Response	Q**	NS			
N × F	NS	NS	*	**	**
		28 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	2.92	0.25	0.12	0.50	0.50
30	2.33	0.45	0.30	0.67	0.33
60	1.50	0.57	0.44	0.77	0.23
90	1.35	0.55	0.47	0.85	0.15
120	1.20	0.58	0.51	0.89	0.11
Response	Q**	Q**	Q**	Q**	Q**
F (days)					
1	1.85	0.47	0.37	0.75	0.25
2	1.72	0.48	0.37	0.73	0.27
3	1.85	0.47	0.35	0.70	0.30
4	2.46	0.45	0.32	0.68	0.32
Response	NS	NS	NS	NS	NS
N × F	NS	NS	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

LAR values. For plants sampled 21 DAS (Fig. 6-29), LAR increased in quadratic fashion in response to applied N at all levels of fertigation frequency. Fertigation frequency did not influence LAR values. The reduction in SLA and LAR values for plants grown with 0 N reflects the reduction in both leaf size and assimilate production (Dubik et al., 1990).

For plants sampled 13 DAS (Fig. 6-30), LMR increased in quadratic fashion in response to applied N under daily fertigation, but when the fertigation frequency was every two to every four days, LMR increased linearly in response to N. Fertigation frequency did not influence LMR values. For plants sampled 21 DAS (Fig. 6-31), LMR increased in quadratic fashion in response to applied N at all levels of fertigation frequency. Leaf mass ratios were not influenced by fertigation frequency. For plants sampled 13 DAS (Fig. 6-32), RMR decreased in quadratic fashion in response to applied N under daily fertigation, but when the fertigation frequency was every two to every four days, RMR decreased linearly in response to N. Fertigation frequency did not influence RMR values. For plants sampled 21 DAS (Fig. 6-33), RMR decreased in quadratic fashion in response to applied N at all levels of fertigation frequency. Root mass ratios were not influenced by fertigation frequency.

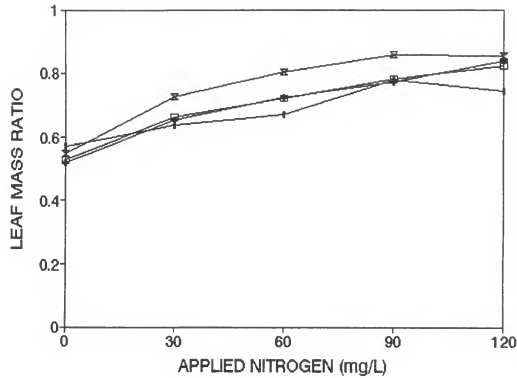


N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treatment means	0.47	0.49	0.54	0.56

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-29. Lettuce transplant leaf area ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.

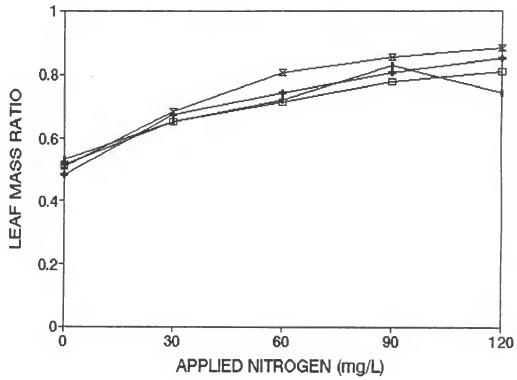


N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treatment means	0.64	0.65	0.66	0.73

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-30. Lettuce transplant leaf mass ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 3, July 1995.

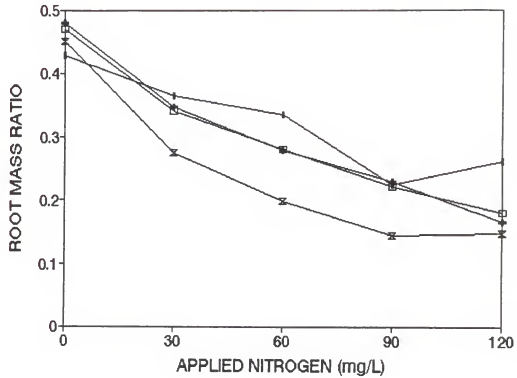


N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treatment means	0.65	0.65	0.67	0.68

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-31. Lettuce transplant leaf mass ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.

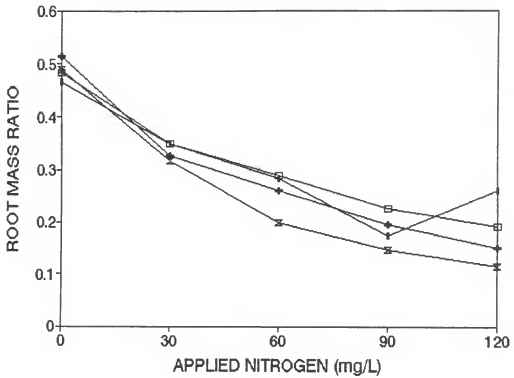


N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treeatment means	0.27	0.34	0.35	0.36

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-32. Lettuce transplant root mass ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 3, July 1995.



N at 30 mg·L^{-1}

Fertigation frequency	1	2	3	4
Treatment means	0.32	0.33	0.35	0.35

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-33. lettuce transplant root mass ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 3, July 1995.

For plants sampled 28 DAS, there were no N by fertigation frequency interactions for LMR and RMR (Table 6-8). Leaf mass ratios increased in quadratic fashion, while RMR decreased in quadratic fashion in response to applied N. Root mass ratios were reduced from 0.5 to 0.1 with applications of 0 to 120 $mg \cdot L^{-1}$ N. Fertigation frequency did not influence LMR or RMR values.

The results of Experiment 3 indicated that, overall, high quality transplants could be produced with 30 $mg \cdot L^{-1}$ N, supplied daily via floatation irrigation, especially when evaluating transplant quality based on dry root mass 28 DAS. Quality transplants had dry root mass of about 28 mg and dry shoot mass of about 75 mg, 28 DAS. Results of Experiment 3 (summer) are different from those obtained in Experiment 2 (spring), where high quality transplants were obtained with 60 $mg \cdot L^{-1}$ applied every other day.

Since different growing seasons provided different results in Experiment 3 compared to Experiment 2, further investigations were deemed necessary in order to determine the seasonal effect of N fertilization practices. Experiment 4 was conducted during the fall, instead of spring and summer, under greenhouse temperatures ranging from 19 to 43 °C (Fig. 6-34). The average daily maximum media temperature was 33 °C, while the average daily minimum media temperature was 26 °C. During the course of the experiment, there were

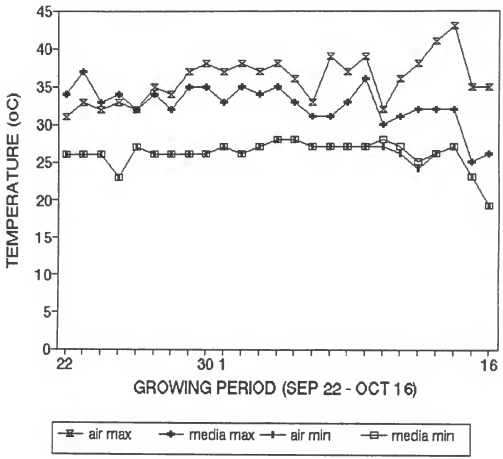


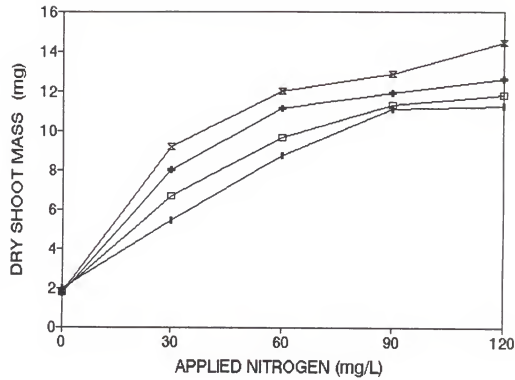
Fig. 6-34. Maximum and minimum air and media temperature during transplant production for Experiment 4, Sep/Oct 1995.

11 sunny and 15 cloudy days, with rain during three of the cloudy days.

Since dry root mass was maximized with 60 $mg \cdot L^{-1}$ in Experiment 4, this N level was used for comparison whenever there were interactions between fertilizer N and fertigation frequency.

For plants sampled 13 DAS (Fig. 6-35) and 21 DAS (Fig. 6-36), dry shoot mass increased in quadratic fashion in response to applied N at all levels of fertigation frequency. For plants sampled 13 DAS, daily fertigation improved dry shoot mass over fertigating every third or fourth day. For plants sampled 21 DAS, dry shoot mass increased when fertigation was more frequent. For plants sampled 28 DAS (Fig. 6-37), dry shoot mass increased linearly in response to N when the fertigation frequency was daily or every second day. When the fertigation frequency was every third or fourth day, dry shoot mass increased in quadratic fashion to applied N. Daily fertigation increased dry shoot mass more than the other frequencies.

For plants sampled 13, 21, and 28 DAS, there were no N by fertigation frequency interactions for dry root mass (Table 6-9). Dry root mass increased in quadratic fashion in response to applied N, regardless of sampling date. The greatest increase in dry root mass occurred between 0 and 30 $mg \cdot L^{-1}$ N. Fertigation frequency did not influence dry root

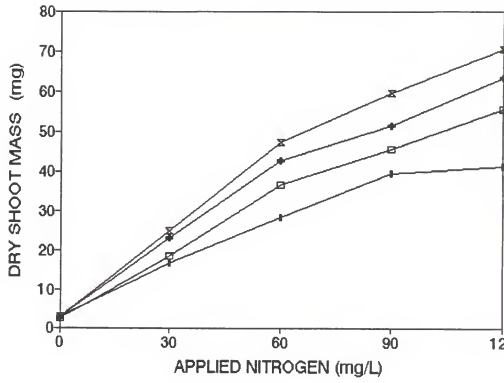


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	8.7	9.6	11.1	12.0

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-35. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 13 days after sowing for Experiment 4, Sep/Oct 1995.

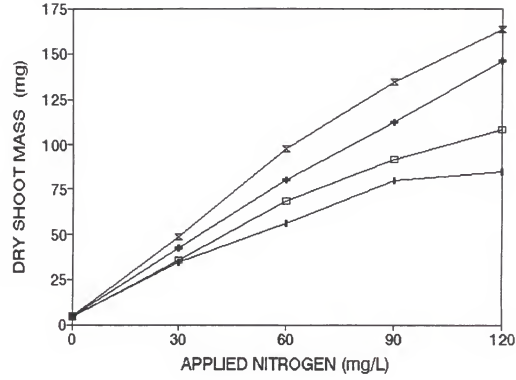


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	28.2	36.3	42.6	47.0

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-36. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.



N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	55.9	68.4	80.0	97.1

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-37. Lettuce transplant dry shoot mass response to N nutrition and fertigation frequency 28 days after sowing for Experiment 4, Sep/Oct 1995.

Table 6-9. Root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 4, September/October 1995.

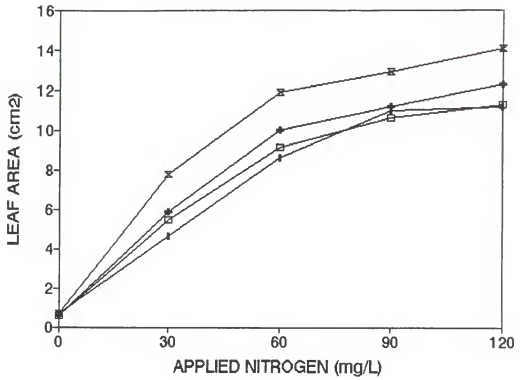
Treatment[z]	Dry root mass (mg)	Pull force (N)	Pulling success (%)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)
		13 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	1.4				
30	3.5				
60	3.6				
90	3.4				
120	3.2				
Response	Q**				
F (days)					
1	2.8				
2	3.0				
3	3.1				
4	3.1				
Response	NS				
N × F	NS			*	
		21 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	2.2			0.81	
30	10.4			0.52	
60	13.2			0.35	
90	13.3			0.28	
120	12.6			0.23	
Response	Q**			Q**	
F (days)					
1	10.3			0.37	
2	10.9			0.43	
3	10.3			0.45	
4	9.9			0.50	
Response	NS			L**	
N × F	NS			NS	*
		28 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	3.7	0.004	0	0.86	0.47
30	19.2	0.013	88	0.48	0.65
60	23.3	0.017	96	0.32	0.64
90	21.8	0.018	98	0.22	0.70
120	18.9	0.018	79	0.16	0.70
Response	Q**	Q**	Q**	Q**	Q**
F (days)					
1	18.2	0.013	73	0.37	0.68
2	18.9	0.016	68	0.39	0.64
3	16.6	0.013	76	0.42	0.61
4	15.7	0.013	69	0.44	0.62
Response	NS	Q*	NS	L*	L*
N × F	NS	NS	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

mass, regardless of sampling date. In Experiments 2 and 3, frequent fertigations increased dry root mass.

For plants sampled 13 DAS (Fig. 6-38), leaf area increased in quadratic fashion in response to applied N at all levels of fertigation frequency. Daily fertigation increased leaf area more than the other frequencies. For plants sampled 21 DAS (Fig. 6-39), leaf area increased in quadratic fashion in response to applied N when fertigation frequency was daily or every fourth day. When fertigation frequency was every two or three days, leaf area increased linearly to applied N. Daily fertigation improved leaf area more than the other frequencies. For plants sampled 28 DAS (Fig. 6-40), leaf area increased in quadratic fashion to applied N only when daily fertigation was applied, but increased linearly when fertigation frequency was every second to every fourth day. Leaf area increased at each level of fertigation frequency, indicating that both N and fertigation frequency were responsible for increased leaf growth.

For plants sampled 28 DAS, there were no N by fertigation frequency interactions for pull force and pulling success (Table 6-9). Pull force increased in quadratic fashion in response to applied N and fertigation frequency. The greatest force was required to pull out transplants fertigated every second day than all other

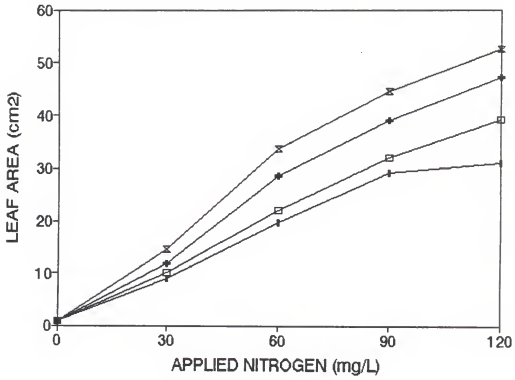


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	8.6	9.1	10.0	11.8

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-38. Lettuce transplant leaf area response to N nutrition and fertigation frequency 13 days after sowing for Experiment 4, July 1995.

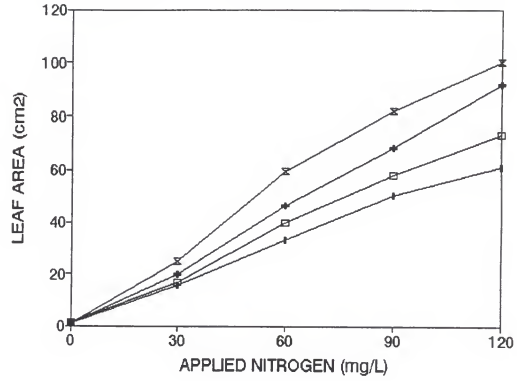


N at 60 mg·L^{-1}

Fertigation frequency	4	3	2	1
Treatment means	19.5	21.8	28.3	33.6

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-39. Lettuce transplant leaf area response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.



N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	32.8	39.4	46.2	59.1

All means are significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

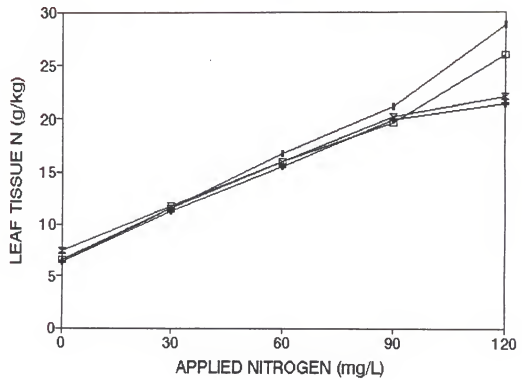
Fig. 6-40. Lettuce transplant leaf area response to N nutrition and fertigation frequency 28 days after sowing for Experiment 4, Sep/Oct 1995.

frequencies. Pulling success increased in quadratic fashion to applied N, but was not influenced by fertigation frequency. Applied N dramatically improved pulling success from 0 % with 0 $mg \cdot L^{-1}$ to 88 % with 30 $mg \cdot L^{-1}$ and 98 % with 90 $mg \cdot L^{-1}$.

For plants sampled 28 DAS (Fig. 6-41), leaf tissue N increased linearly in response to applied N. Fertigation frequency did not influence N concentrations in transplant leaves when 60 $mg \cdot L^{-1}$ N was used.

For plants sampled 13 DAS (Fig. 6-42), RSR increased in quadratic fashion in response to applied N, regardless of fertigation frequency. Fertigating every fourth day increased RSR values compared to daily fertigation. For plants sampled 21 and 28 DAS, there were no N by fertigation frequency interactions for RSR (Table 6-9). Root:shoot ratios decreased in quadratic fashion in response to applied N. Root:shoot ratios also increased with less frequent fertigations.

For plants grown to 21 DAS (Fig 6-43), RGR increased in quadratic fashion in response to applied N at all levels of fertigation frequency. Daily fertigation led to greater RGR values than fertigating every fourth day. For plants grown to 28 DAS, there were no N by fertigation frequency interactions for RGR (Table 6-9). Relative growth rate

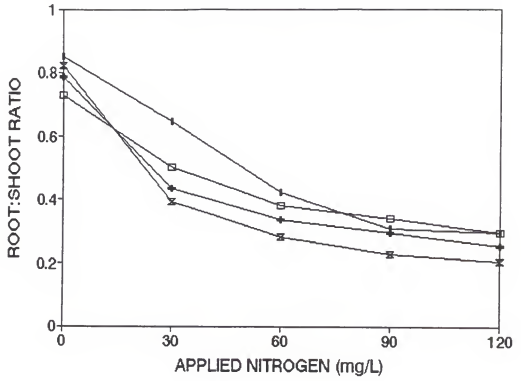


N at 60 mg·L⁻¹

Fertigation frequency	2	1	3	4
Treatment means	1.55	1.59	1.59	1.67

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-41. Lettuce transplant leaf tissue N response to N nutrition and fertigation frequency 28 days after sowing for Experiment 4, Sep/Oct 1995.

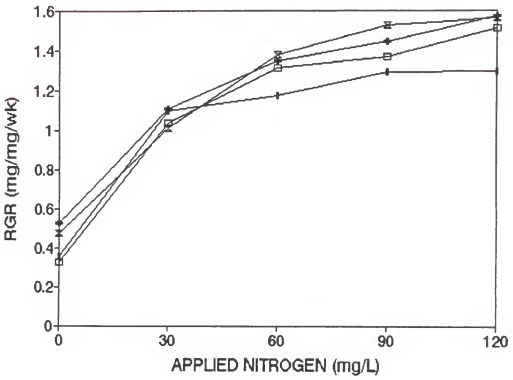


N at 60 mg·L⁻¹

Fertigation frequency	1	2	3	4
Treatment means	0.28	0.33	0.38	0.42

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-42. Lettuce transplant root:shoot ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 4, Sep/Oct 1995.



N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	1.17	1.31	1.35	1.38

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

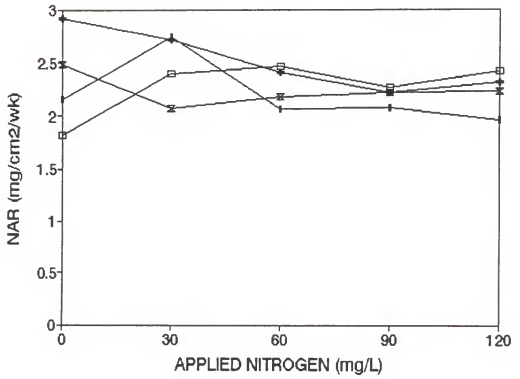
Fig. 6-43. Lettuce transplant relative growth rate response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.

increased in quadratic fashion in response to applied N, but decreased linearly when the interval between each fertigation increased.

For plants grown to 21 DAS (Fig 6-44), NAR decreased in quadratic fashion in response to applied N under daily fertigation, but decreased linearly when fertigation was every second day. However, NAR was unaffected by N when fertigation was every third or fourth day. Fertigation frequency did not affect NAR values. For plants grown to 28 DAS, there were no N by fertigation frequency interactions for NAR (Table 6-10). Net assimilation rate decreased in quadratic fashion in response to applied N, but was unaffected by fertigation frequency.

For plants sampled 13 DAS, there were no N by fertigation frequency interactions for SLA (Table 6-10). Specific leaf area responded in quadratic fashion to applied N and to fertigation frequency. Fertigating every day or every fourth day led to greater SLA values compared to fertigating every second or third day. For plants sampled 21 DAS (Fig. 6-45) and 28 DAS (Fig. 6-46), SLA increased in quadratic fashion in response to applied N at all levels of fertigation frequency. In general, fertigation frequency did not affect SLA values.

For plants sampled 13 and 28 DAS, there were no N by fertigation frequency interactions for LAR (Table 6-10).



N at 60 mg·L⁻¹

Fertigation frequency	4	1	2	3
Treatment means	2.07	2.18	2.40	2.46

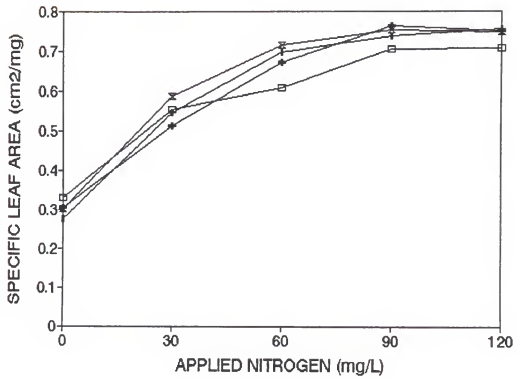
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-44. Lettuce transplant net assimilation rate response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.

Table 6-10. Influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 4, Sep/Oct 1995.

Treatment[z]	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
		13 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0		0.36	0.20		
30		0.82	0.55		
60		0.96	0.71		
90		0.97	0.75		
120		0.98	0.78		
Response		Q**	Q**		
F (days)					
1		0.84	0.65		
2		0.78	0.58		
3		0.80	0.58		
4		0.84	0.59		
Response		Q**	Q**		
N × F		NS	NS	**	**
		21 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0				0.55	0.45
30				0.66	0.34
60				0.74	0.26
90				0.78	0.22
120				0.82	0.18
Response				Q**	Q**
F (days)					
1				0.75	0.25
2				0.72	0.28
3				0.70	0.30
4				0.68	0.32
Response				L**	L**
N × F	**	**	**	NS	NS
		28 Days After Sowing			
N ($mg \cdot L^{-1}$)					
0	3.04		0.15	0.53	0.46
30	1.92		0.32	0.68	0.32
60	1.38		0.45	0.76	0.24
90	1.30		0.51	0.82	0.18
120	1.22		0.57	0.86	0.14
Response	Q**		Q**	Q**	Q**
F (days)					
1	1.76		0.41	0.76	0.24
2	1.74		0.39	0.74	0.26
3	1.73		0.40	0.73	0.27
4	1.86		0.40	0.71	0.29
Response	NS		NS	L**	L**
N × F	NS	**	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

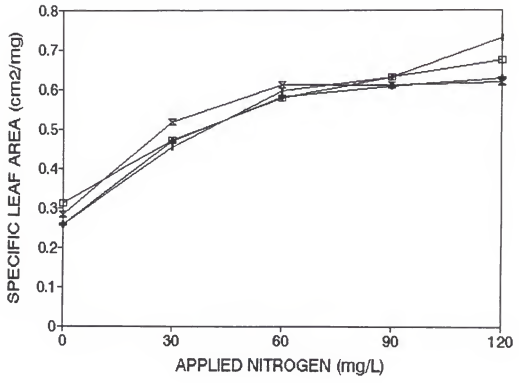


N at 60 mg·L⁻¹

Fertigation frequency	1	2	3	4
Treatment means	0.61	0.67	0.70	0.71

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-45. Lettuce transplant specific leaf area response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.



N at 60 mg·L⁻¹

Fertigation frequency	3	2	4	1
Treatment means	0.58	0.58	0.59	0.61

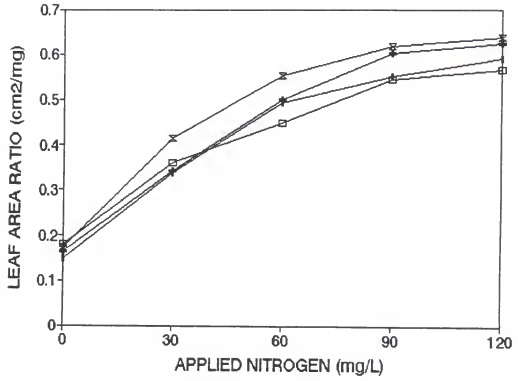
Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-46. Lettuce transplant specific leaf area response to N nutrition and fertigation frequency 28 days after sowing for Experiment 4, Sep/Oct 1995.

Leaf area ratios increased in quadratic fashion in response to applied N. For plants sampled 13 DAS, daily fertigation increased LAR, while for plants sampled 28 DAS, fertigation frequency did not influence LAR values. For plants sampled 21 DAS (Fig. 6-47), LAR increased in quadratic fashion in response to applied N at all levels of fertigation frequency. Daily fertigation resulted in greater LAR values than fertigating every third or fourth day.

For plants sampled 13 DAS, LMR (Fig. 6-48) increased in quadratic fashion, while RMR (Fig. 6-49) decreased in quadratic fashion in response to applied N. Daily fertigation led to greater LMR values than fertigating every third or fourth day. However, fertigating every third or fourth day led to greater RMR values than daily fertigation. For plants sampled 21 and 28 DAS, there were no N by fertigation frequency interactions for LMR and RMR (Table 6-10). Leaf mass ratios increased in quadratic fashion, while RMRs decreased in quadratic fashion in response to applied N. Leaf mass ratios decreased when the interval between each fertigation was increased, while RMRs increased when the interval between each fertigation increased.

Results of Experiment 4 in the fall indicated that, overall, high quality transplants could be produced with 60 $mg \cdot L^{-1}$ N, supplied daily to every fourth day via floatation irrigation, especially when evaluating transplant quality

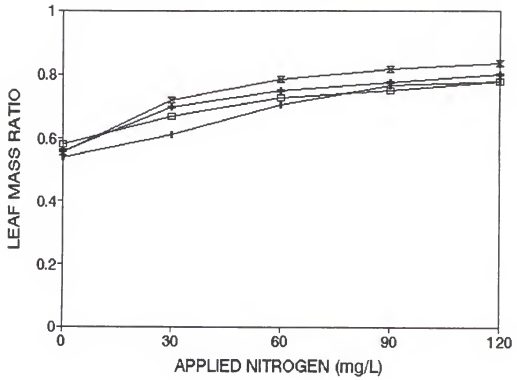


N at 60 mg·L^{-1}

Fertigation frequency	3	4	2	1
Treatment means	0.45	0.49	0.50	0.55

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-47. Lettuce transplant leaf area ratio response to N nutrition and fertigation frequency 21 days after sowing for Experiment 4, Sep/Oct 1995.

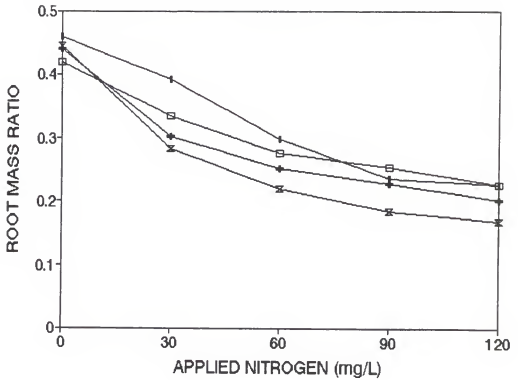


N at 60 mg·L⁻¹

Fertigation frequency	4	3	2	1
Treatment means	0.70	0.72	0.75	0.78

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-48. Lettuce transplant leaf mass ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 4, Sep/Oct 1995.



N at 60 mg·L⁻¹

Fertigation frequency	1	2	3	4
Treatment means	0.22	0.25	0.28	0.30

Means connected by a common line are not significantly different at 5 % level.
Mean separation of fertigation frequency by Bonferroni test.

Fig. 6-49. Lettuce transplant root mass ratio response to N nutrition and fertigation frequency 13 days after sowing for Experiment 4, Sep/Oct 1995.

based on dry root mass 28 DAS. Quality transplants had dry root mass of about 23 mg and dry shoot mass of about 75 mg, 28 DAS.

Regardless of season of the year, there were similar trends in the response of dry shoot mass to applied N and to fertigation frequency. However, the greatest dry shoot mass was obtained in Experiment 3, which was conducted during the summer, potentially due to the greater light intensities and temperatures.

The concentration of N necessary for obtaining high quality transplants, especially in terms of root growth, was seasonally related. High quality transplants were obtained with 60 $mg \cdot L^{-1}$ N in Experiment 2 (Feb/Mar) and Experiment 4 (Sep/Oct) supplied every other day, but with 30 $mg \cdot L^{-1}$ N supplied daily in Experiment 3 (July). The corresponding levels of tissue N at these N concentrations were approximately 20, 15, and 16 $g \cdot kg^{-1}$ for Experiments 2, 3, and 4, respectively.

The seasonal response of dry root mass to applied N was probably related to proportionally greater shoot growth compared to root growth during July due to higher temperatures and probably higher sunlight intensities for a longer duration than the other two growing periods. Shoots grew at the expense of root growth. Roots are, therefore, weaker sink during periods of excellent shoot growth. Root

growth was improved at lower minimum temperatures (20 °C) than at higher minimum temperatures (26 or 28 °C). However, pulling success was adequate in both Experiments 2 and 4, compared to Experiment 3, indicating that very high temperatures were detrimental to pulling success. When considering the optimum N level of 60 $mg \cdot L^{-1}$ for fall and spring, the optimum RSR ranged between 0.24 and 0.27. The optimum RSR during summer was 0.33 with 30 $mg \cdot L^{-1}$ N.

Regardless of season, RGR increased in response to applied N, while NAR decreased in response to N. However RGR and NAR values were greater at 21 than at 28 DAS, implying that younger transplants had higher efficiency of growth than older ones. Specific leaf area and LAR were less affected by seasonal differences, and they were both improved by applied N as well as frequent fertigations.

In Experiment 2 (spring) and Experiment 4 (fall), 60 $mg \cdot L^{-1}$ N applied every second day through floatation irrigation generally was shown to produce high quality transplants. Nitrogen at 60 $mg \cdot L^{-1}$ applied every other day was next used to determine if N applied at different times during the growth cycle for transplant production was a factor in promoting root growth. Growth at this N level was compared to growth of transplants receiving no N.

Experiment 5 was conducted during the spring, similar to Experiment 2, under greenhouse temperatures ranging from

16 to 37 °C (Fig. 6-50). The average daily maximum media temperature was 32 °C, while the average daily minimum media temperature was 22 °C. During the course of the trial, there were 19 sunny and 8 cloudy days, with rain during three of the cloudy days.

For plants sampled 22 DAS, fresh shoot mass was least at 0 N, and greatest at 60 $mg \cdot L^{-1}$ N applied every two days over a 28-day growing period (Table 6-11). Dry shoot mass was also least at 0 N during this sampling date, but greatest at 60 $mg \cdot L^{-1}$ N applied at the first 14 days or the entire 28-day growing period. For plants sampled 28 DAS, fresh and dry shoot mass were least at 0 N, and greatest at 60 $mg \cdot L^{-1}$ N applied every two days for the entire growing period. Plants grown with 60 $mg \cdot L^{-1}$ N during the first 14 days, allocated more dry matter to shoots than plants grown with 60 $mg \cdot L^{-1}$ N applied every four days for a 28-day growing period.

For plants sampled 22 DAS, transplants which received N at the second half of the growing period, apparently partitioned N for shoot growth rather than root growth. Roots of these transplants were not any larger than those grown with 0 N. For plants sampled 22 and 28 DAS, fresh or dry root mass was greatest with 60 $mg \cdot L^{-1}$ N applied every two days over the entire growing period. By the last sampling date, root length, area, and diameter were least

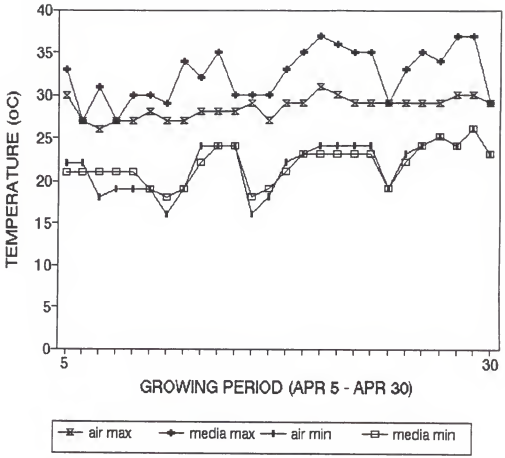


Fig. 6-50. Maximum and minimum air and media temperature during transplant production for Experiment 5, April 1995.

Table 6-11. Root and shoot characteristics of lettuce transplants as affected by timing of N application for Experiment 5, April 1996.

Timing of nitrogen application[z]	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Root length (cm)	Root area (cm^2)	Root diameter (mm)	Leaf area (cm^2)	Plant height (mm)	Pull force (N)	Pulling success (%)
					22 Days After Sowing						
T_1	26	3.8	33	3.5				0.8	10.6		
T_2	674	70.6	241	20.8				21.0	54.3		
T_3	150	9.2	58	4.0				5.2	28.9		
T_4	475	45.8	203	17.2				15.0	45.0		
T_5	1168	71.2	315	24.7				34.3	70.8		
LSD (0.05)	56	5.0	25	1.7				1.6	3.7		
					28 Days After Sowing						
T_1	30	5.1	42	4.9	58	4.8	0.26	1.0	11.4	0.006	5
T_2	861	104.6	338	35.4	309	33.7	0.32	26.2	59.3	0.021	100
T_3	692	39.9	208	14.5	240	21.9	0.29	22.5	63.1	0.012	5
T_4	820	78.7	352	32.6	312	30.5	0.31	24.7	54.2	0.021	100
T_5	1960	132.8	559	45.6	412	42.9	0.33	59.4	86.7	0.028	100
LSD (0.05)	107	5.8	37	2.9	24	2.4	0.01	2.7	4.6	0.003	10

[z]T_1 = zero N irrigated every two days, T_2 = 60 $mg \cdot L^{-1}$ N irrigated every two days for the first 14 days of a 28-day growing period, T_3 = 60 $mg \cdot L^{-1}$ N irrigated every two days during the last 14 days of a 28-day growing period, T_4 = 60 $mg \cdot L^{-1}$ N applied every four days, but irrigation being every two days, T_5 = 60 $mg \cdot L^{-1}$ N irrigated every two days.

with 0 N, and greatest with 60 $mg \cdot L^{-1}$ N applied every two days for the entire growing period.

For plants sampled 22 and 28 DAS, both leaf area and transplant height were least with 0 N and greatest with 60 $mg \cdot L^{-1}$ N applied over the 28-day growing period (Table 6-11). By the termination of the experiment, transplants grown with 0 N or with 60 $mg \cdot L^{-1}$ N applied at the second half of a 28-day growing period, could not be easily pulled from the transplant flat. Transplants broke after only minimal pull force was applied compared to the treatments which pulled successfully.

Petiole sap NO_3-N was not sampled for transplants grown with 0 N because they were too small to obtain a necessary quantity of sap for testing (Table 6-12). The greatest concentration of NO_3-N was in leaves of transplants grown with 60 $mg \cdot L^{-1}$ N applied every four days. However, the highest concentration of tissue N was obtained in leaves of transplants which received N only in the second half of a 28-day growing period, probably because N was now available.

For plants sampled 22 DAS, RSR was greatest with 0 N, and least with 60 $mg \cdot L^{-1}$ N applied every second day only in the first half of a 28-day growing period. For plants sampled 28 DAS, RSR continued to be greatest with 0 N, but least with 60 $mg \cdot L^{-1}$ N applied every two days for a 28-day growing period.

Table 6-12. Influence of timing of N application on growth characteristics of lettuce transplants, April 1996.

Timing of nitrogen application[z]	Petiole sap nitrate ($mg \cdot L^{-1}$)	Leaf tissue N ($g \cdot kg^{-1}$)	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
				22 Days After Sowing					
T_1			0.93			0.21	0.11	0.52	0.48
T_2			0.29			0.30	0.23	0.77	0.23
T_3			0.44			0.57	0.39	0.70	0.30
T_4			0.38			0.33	0.24	0.73	0.27
T_5			0.34			0.48	0.36	0.74	0.26
LSD (0.05)			0.06			0.03	0.02	0.02	0.02
				28 Days After Sowing					
T_1	-	4.9	0.97	0.34	3.31	0.19	0.10	0.51	0.49
T_2	514	6.4	0.38	0.43	2.07	0.25	0.19	0.75	0.25
T_3	440	22.5	0.36	1.42	3.50	0.56	0.41	0.73	0.27
T_4	559	8.7	0.41	0.57	2.49	0.31	0.22	0.71	0.29
T_5	361	16.8	0.34	0.62	1.81	0.45	0.33	0.74	0.26
LSD (0.05)	73	1.0	0.05	0.13	1.10	0.02	0.02	0.02	0.02

[z]T_1 = zero N irrigated every two days, T_2 = 60 $mg \cdot L^{-1}$ N irrigated every two days for the first 14 days of a 28-day growing period, T_3 = 60 $mg \cdot L^{-1}$ N irrigated every two days during the last 14 days of a 28-day growing period, T_4 = 60 $mg \cdot L^{-1}$ N applied every four days, but irrigation being every two days, T_5 = 60 $mg \cdot L^{-1}$ N irrigated every two days.

For plants grown to 28 DAS, RGR was least with 0 N, and greatest with 60 $mg \cdot L^{-1}$ N applied every two days in the second half of a 28-day growing period. Net assimilation rate was least with 60 $mg \cdot L^{-1}$ N applied every second day over the entire growing period, and greatest when N was applied in the second half of a 28-day growing period. Therefore, transplants which received N during the second half of a 28-day growing period had a high efficiency for growth due to the now available N.

For plants sampled 22 and 28 DAS, SLA and LAR were greatest with 60 $mg \cdot L^{-1}$ N applied every second day during the second half of a 28-day growing period. For plants sampled 22 DAS, LMR was greatest with 60 $mg \cdot L^{-1}$ N applied every second day during the first week of a 28-day growing period, and least at 0 N. For plants sampled 22 DAS, transplants grown with 0 N had the greatest RMR values, followed by plants produced with 60 $mg \cdot L^{-1}$ N applied during the second half of a 28-day growing period. By 28 DAS, RMR continued to be greatest in plants grown with 0 N.

Experiment 5 demonstrated that frequent applications (every second day) of 60 $mg \cdot L^{-1}$ N throughout the period of transplant growth led to more root growth than applying N at the first half or last half of a 28-day growing period. Also, less frequent applications (every fourth day) of N reduced root and shoot growth compared to applying N every

other day. However, all transplants could be pulled from all the treatment flats except for 0 N for 28 days or 60 $mg \cdot L^{-1}$ N applied in the second half of a 28-day transplant growing period. Pull force ranged from 0.021 to 0.028 N for quality transplants. It appeared that N supplied earlier was needed for continued root growth during the 28-day growing period. Widders (1989) reported that for tomato transplants grown under a moderately low mineral nutrient regime, increasing N during the last 10 days before transplanting led to the best quality transplants.

Field Experiments

Plants from Greenhouse Experiment 2 (spring) and Experiment 4 (fall) were grown to maturity to evaluate the effects of pretransplant N and fertigation frequency on earliness, yield and lettuce head quality.

Harvesting was done at head maturity in the spring crop of Experiment 1 on 11 May or 16 May (Table 6-13). Plants grown with pretransplant N at 0 or 30 $mg \cdot L^{-1}$ were harvested 54 days after transplanting (DAT). Others were harvested 49 DAT. At harvest, there were no N by fertigation frequency interactions for head mass or head quality characteristics. Head mass was increased by pretransplant N to 60 $mg \cdot L^{-1}$, but was unaffected by pretransplant fertigation frequency.

Table 6-13. Effects of N nutrition and fertigation frequency during transplant production on lettuce head mass and head quality characteristics for Experiment 1, harvested 11 or 16 May 1995.

Treatment[z]	Head mass	Firm rating[y]	Head height	Head diameter	Stem diameter	Core length	Leaf tissue N
	(g)	(1-5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)
N ($mg \cdot L^{-1}$)							
0	635	4.8	129	123	27	71	24.7
30	765	5.0	135	137	31	96	24.6
60	801	4.8	140	134	29	57	24.7
90	798	4.8	142	133	28	57	24.6
120	772	4.7	140	132	29	56	24.2
Response	Q**	NS	Q**	Q**	Q**	Q**	NS
F (days)							
1	731	4.8	137	132	29	66	25.1
2	759	4.8	138	133	29	67	24.6
3	764	4.8	137	131	29	67	24.0
4	762	4.9	138	131	28	69	24.6
Response	NS	NS	NS	NS	NS	NS	NS
N × F	NS	NS	NS	NS	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
[y]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

Lettuce head height, head diameter, and stem diameter were increased by pretransplant N. Plants grown with 0 or 30 $mg \cdot L^{-1}$ pretransplant N were late maturing and consequently had elongated cores at harvest. Therefore, larger plants at transplanting due to pretransplant N can be important for earliness. At harvest, tissue N levels were equal regardless of pretransplant N applied, and ranged from 24 to 25 $g \cdot kg^{-1}$. Hochmuth et al. (1991) reported values of 20 to 30 $g \cdot kg^{-1}$ (soil type not reported) to be indicative of an adequate range for crisphead lettuce.

All treatments in the fall crop of Experiment 2 were harvested in December, 64 DAT (Table 6-14). There were no N by fertigation frequency interactions for head mass or head quality characteristics. Head mass was increased by pretransplant N to 90 $mg \cdot L^{-1}$, but was unaffected by pretransplant fertigation frequency.

Firmness, head height, head diameter, and stem width were all increased by pretransplant N. Core length was enlarged, indicating an effect of pretransplant N on earliness. Neither of these quality parameters were influenced by pretransplant fertigation frequency.

Leaf tissue N was not influenced by pretransplant fertigation frequency. Leaf tissue N was greatest in plants with no pretransplant N. This was probably a dilution effect since heads were smaller at this level than all the other

Table 6-14. Effects of N nutrition and fertigation frequency during transplant production on lettuce head mass and head quality characteristics for Experiment 2, harvested 20 December 1995.

Treatment[z]	Head mass	Firm rating[y]	Head height	Head diameter	Stem diameter	Core length	Leaf tissue N
	(g)	(1–5)	(mm)	(mm)	(mm)	(mm)	($g \cdot kg^{-1}$)
N ($mg \cdot L^{-1}$)							
0	400	3.3	106	112	21	27	36.4
30	618	4.8	116	118	27	39	34.2
60	663	4.8	120	120	28	47	34.4
90	688	4.7	120	120	29	55	34.2
120	650	4.8	119	118	30	53	34.1
Response	Q**	Q**	Q**	Q**	Q**	Q**	Q*
F (days)							
1	599	4.4	117	118	27	46	35.2
2	598	4.4	115	116	27	45	34.4
3	605	4.6	118	120	27	45	34.7
4	613	4.5	115	117	26	41	34.2
Response	NS	NS	NS	NS	NS	NS	NS
N × F	NS	NS	NS	NS	NS	NS	NS

[z]N = nitrogen; F = fertigation frequency.
[y]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Quadratic (Q).
NS, *, **Nonsignificant (NS) or significant at 5% (*), 1% (**) levels.

treatments. Hochmuth et al. (1991) reported values of 20 to 30 $g \cdot kg^{-1}$ (soil type not reported) to be indicative of an adequate range for crisphead lettuce. The values of tissue N in this experiment were about 34 $g \cdot kg^{-1}$, indicating that sufficient N was supplied to the plants.

The lettuce production season is from September to May in Florida. Consequently, if plants are left later than mid May they will bolt and in north Florida if they are unprotected and left later than mid December, they will likely freeze. Plants which were grown with 0 or 30 $mg \cdot L^{-1}$ pretransplant N were small at transplanting and matured later than those produced with at least 60 $mg \cdot L^{-1}$ N during spring planting. Plants were, therefore, harvested later and consequently had elongated cores, which is an indicator of poor lettuce quality. During the fall planting, all plants were harvested at the same time even though those which were produced with no pretransplant N were less mature. If the plants were left longer in the field, they would have frozen. A similar result was described in Chapters 3 and 5 where plants produced with no pretransplant P or pretransplant N matured later because they were small at transplanting. Earliness is extremely important to the lettuce producer and transplant nutrition can affect earliness.

Summary

In order to determine N concentration and fertigation frequency required for production of high quality transplants and subsequent high yield, 'South Bay' lettuce transplants were fertigated every day or every second, third, or fourth day with N at 0, 30, 60, 90, or 120 $mg \cdot L^{-1}$. A quality transplant is defined as one that can fill a 10.9 cm^3 tray cell with roots, to facilitate easy removal of transplants from the transplant flat, and for rapid field establishment. Nitrogen concentration and fertigation frequency that resulted in quality transplants were subsequently used to determine if N applied at different times during transplant growth, was a factor in promoting root growth. To avoid inconsistency in the duration of the light period, natural photoperiod was extended to 16 h in all experiments.

Regardless of fertigation frequency, applied N increased dry shoot mass, leaf area, pull force, pulling success, leaf tissue N, RGR, SLA, LAR, and LMR, but reduced RSR, NAR, and RMR. In general, the effect of N on transplant growth was enhanced by frequent fertigations. Nitrogen at 30 $mg \cdot L^{-1}$ during the summer or 60 $mg \cdot L^{-1}$ during fall and spring, maximized root growth, provided that fertigation frequency was daily (summer) or every other day (spring).

In general, pulling success was reduced during summer compared to spring or fall crops. Low pull force was associated with low pulling success due to the root systems not pulling out completely from the transplant flat. Quality transplants had dry shoot mass of no more than 136 mg, dry root mass of at least 23 mg, RSRs ranging from 0.30 to 0.48, with leaf tissue N ranging from 16 to 23 $g \cdot kg^{-1}$.

Pretransplant N of 60 $mg \cdot L^{-1}$ led to increased head mass at harvest and reduced time to maturity. Earliness is extremely important to the lettuce grower and transplant nutrition can affect earliness.

In investigating the significance of when N was applied during transplant growth, 60 $mg \cdot L^{-1}$ N applied every second or every fourth day throughout the period of transplant production or at the first half of a 28-day growing period, led to more root growth compared to N applied at the second half. Therefore, N is more important earlier in growth than later on, for production of quality transplants.

This work demonstrated that at least 60 $mg \cdot L^{-1}$ N applied every other day via floatation irrigation to a peat+vermiculite media was required for production of high quality transplants during fall and spring, which led to more lettuce head mass at harvest and reduced time to maturity. During summer, 30 $mg \cdot L^{-1}$ N applied daily was adequate for production of quality transplants.

CHAPTER 7

SUMMARY

Lettuce transplants grown with floatation irrigation system often show limited root growth, resulting in root systems not pulling out completely from the transplant flat, and poor establishment in the field. In the present investigation, 'South Bay' lettuce transplants, grown in a peat+vermiculite media in the greenhouse, were fertilized with varying concentrations of N, P, and K via floatation irrigation at selected fertigation frequencies, to determine optimum nutrient and water management requirements for production of high quality lettuce transplants, with sufficient roots to fill a 10.9 cm^3 tray cell, and that ultimately establish in the field rapidly. To avoid inconsistency in the duration of the light period, natural photoperiod was extended to 16 h in all experiments.

To determine the optimum P concentration necessary for production of high quality transplants, plants were propagated by floating flats in nutrient solution containing either 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ P in summer and fall experiments, and either 0, 15, 30, 60, or 90 $mg \cdot L^{-1}$ P in

factorial combination with 60 or 100 $mg \cdot L^{-1}$ N in a winter experiment. When the concentration of P in the media (saturated paste extract) was more than 12 $mg \cdot kg^{-1}$ (summer experiment), P at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ sub-irrigated every two to four days, did not influence fresh or dry root mass. However, when the concentration of P in the media was about 0.5 $mg \cdot kg^{-1}$ (fall experiment), fresh and dry root mass increased with each level of P fertigatigated every two to four days. When the fertigation frequency was every two days (winter), fresh and dry root mass increased in response to 15 $mg \cdot L^{-1}$ P, with no further increases in root mass at higher P concentrations up to 90 $mg \cdot L^{-1}$ even though the media P concentration was only 0.4 $mg \cdot kg^{-1}$.

The major transplant growth responses to applied P occurred between 0 and 15 $mg \cdot L^{-1}$ P, regardless of fertigation frequency and media P concentration. Added P increased fresh and dry shoot mass, root length and area, leaf area, pulling success, leaf tissue P, relative growth rate (RGR), specific leaf area (SLA), leaf area ratio (LAR), leaf mass ratio (LMR), but reduced root:shoot ratio (RSR), net assimilation rate (NAR), and root mass ratio (RMR). Only about 30 % of plants grown with 0 P could be pulled from the transplant flat, compared to approximately 90 % pulling success with any level of applied P. Quality transplants had dry shoot mass of not more than 115 mg, dry root mass of at

least 21 mg. Root:shoot ratio of 0.25 and leaf tissue P of 4 $g \cdot kg^{-1}$ can be considered optimum for production of high quality transplants.

All pretransplant P concentrations had similar effects of increasing head mass at harvest time, and reducing time to maturity regardless of season. At transplanting, plants grown with pretransplant P were larger than those grown with no P. Therefore, larger plants at transplanting led to earlier harvests, and larger head size at harvest.

This work demonstrated that at least 15 $mg \cdot L^{-1}$ P, supplied every two days via floatation irrigation, was required for production of high quality lettuce transplants in a peat+vermiculite media that contained less than 0.5 $mg \cdot kg^{-1}$ P (saturated paste extract).

Floatation fertigation with K at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ K applied every two to four days, increased fresh and dry root mass when the concentration of K in the media (saturated paste extract) was less than 15 $mg \cdot kg^{-1}$, but with higher media K (24 $mg \cdot kg^{-1}$), root mass was unaffected. Fresh and dry shoot mass, leaf area, RSR, RGR, LMR, and RMR were unaffected by applied K, regardless of the initial K concentration in the media. Plant available K in the media (11 to 24 $mg \cdot kg^{-1}$ K in the saturated paste extract) may have supplied the K needs during lettuce transplant growth and development. In an experiment comparing 60 with 100 $mg \cdot L^{-1}$ N

at various levels of K, applied K did not influence SLA at 60 $mg \cdot L^{-1}$ N, while at 100 $mg \cdot L^{-1}$ N, SLA increased at each level of applied K. Lettuce growth and yield in the field was not affected by pretransplant K fertilization.

Since transplants had minimal response to K in peat+vermiculite media, peat+rockwool media (2.5 $mg \cdot kg^{-1}$ water extractable K) was used to investigate lettuce transplant growth in a mix inherently low in K. The benefits in promoting improved lettuce growth by supplementary light for 16 h or extended photoperiod to 16 h were also evaluated.

Potassium at 60 $mg \cdot L^{-1}$ increased shoot and root mass, leaf area, petiole sap K, leaf tissue K, and RGR, but did not influence RSR, SLA, LAR, LMR, or RMR. It was observed that transplants grown with 0 K in peat+rockwool mix could not be easily removed from the transplant flat. Stems broke during removal, rather than breaking at the root-shoot interface similar to transplants that received no N or P fertilizer. Under periods of low light intensity, supplemental lighting (250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux) led to improved transplant root growth.

Potassium fertilizer programs revealed that supplemental K may not be required in a peat+vermiculite mix using a floatation irrigation system, since vermiculite supplied adequate K to the growing seedlings. In a

peat+rockwool mix, at least 60 $mg \cdot L^{-1}$ K is recommended to produce a transplant with sufficient roots and a strong stem to facilitate ease of transplant removal from the transplant flat.

Nitrogen was the nutrient with the greatest impact on lettuce transplant growth. Nitrogen at 0, 15, 30, 45, or 60 $mg \cdot L^{-1}$ sub-irrigated every two to four days, increased fresh and dry shoot and root mass, leaf area, transplant height, stem diameter, RGR, SLA, LAR, and LMR, but reduced RSR, NAR, and RMR. Transplants grown with 60 $mg \cdot L^{-1}$ N were about 80 mm tall, had dry shoot mass ranging from 55 to 73 mg, dry root mass ranging from 15 to 22 mg, and RSR ranging from 0.23 to 0.32, and leaf tissue N ranging from 15 to 17 $g \cdot kg^{-1}$. It was observed that transplants could not be easily pulled from the transplant flat at all levels of applied N in these experiments. When the mean dry root mass was less than 20 mg, pulling success was observed to be even more reduced. Nitrogen at 60 $mg \cdot L^{-1}$ was perhaps not adequate with the irrigation programs used. Therefore, additional experiments were designed to investigate the effect of N fertilization to 120 $mg \cdot L^{-1}$ and fertigation frequency on lettuce transplant growth and development.

In the field, lettuce head mass was improved at harvest by pretransplant N. The heaviest heads were obtained from plants grown with 60 $mg \cdot L^{-1}$ pretransplant N. In the

greenhouse, transplants grown with 60 $mg \cdot L^{-1}$ N also had the greatest shoot and root mass.

Nitrogen fertilizer programs revealed that at least 60 $mg \cdot L^{-1}$ N supplied every two to four days via floatation irrigation, was required for improved transplant shoot and root growth in a peat+vermiculite mix low in NO_3-N. Transplants grown with 60 compared to 15 $mg \cdot L^{-1}$ N were larger at transplanting, resulting in improved head mass at harvest.

To determine the optimum N concentration and fertigation frequency, transplants were fertigated every day or every second, third, or fourth day with N at 0, 30, 60, 90, or 120 $mg \cdot L^{-1}$. Nitrogen concentration and fertigation frequency that resulted in quality transplants were subsequently used to determine if N applied at different times during transplant growth, was a factor in promoting root growth.

In order to determine the seasonal effect of N fertilization practices on lettuce transplant growth, the N by fertigation frequency experiments were conducted in spring, summer and fall. Regardless of fertigation frequency, N from 30 to 120 $mg \cdot L^{-1}$ increased dry shoot and root mass, leaf area, pulling success, leaf tissue N, RGR, SLA, LAR, and LMR, but reduced RSR, NAR, and RMR. The concentration of N necessary for obtaining high quality

transplants, especially in terms of root growth, was seasonally related. High quality transplants were obtained with daily fertigation of 30 $mg \cdot L^{-1}$ N in summer, and with 60 $mg \cdot L^{-1}$ N in the fall or spring, supplied every other day via floatation irrigation. Therefore, N concentration and fertigation frequency must be considered together.

Pulling success was improved from less than 16 % with 0 N to about 88 % with the initial N application of 30 $mg \cdot L^{-1}$ in the spring and fall experiments. In general, pulling success was reduced during summer compared to spring or fall crops, indicating that very high temperatures (average daily maximum media temperature of 38 °C) were detrimental to pulling success. Quality transplants had dry shoot mass of not more than 136 mg, dry root mass of at least 23 mg, RSRs ranging from 0.30 to 0.48, with leaf tissue N ranging from 16 to 23 $g \cdot kg^{-1}$.

Pretransplant N, but not fertigation frequency, improved head mass at harvest and reduced time to maturity. This is of particular significance in northern Florida where the growing period for lettuce is short. Earliness is extremely important to the grower and transplant nutrition can affect earliness.

In investigating the significance of when N was applied during transplant growth, 60 $mg \cdot L^{-1}$ N applied every second or every fourth day throughout the period of transplant

production or at the first half of a 28-day transplant production period, improved root growth compared to N applied at the second half. Transplants had 100 % pulling success compared to 5 % pulling success when transplants were grown with 0 N or with 60 $mg \cdot L^{-1}$ N applied every second day during the second half of a 28-day growing period. Therefore, N is more important earlier in growth for production of quality transplants. Quality transplants were 54 mm (N applied every fourth day) to 87 mm tall (N applied every second day), had dry shoot mass ranging from 79 to 133 mg, dry root mass ranging from 33 to 46 mg, RSRs ranging from 0.34 to 0.41, with leaf tissue N ranging from 5 $g \cdot kg^{-1}$ (N applied during the first half of a 28-day growing period) to 17 $g \cdot kg^{-1}$ (N applied for the entire 28-day period). Transplant height, therefore, could be controlled by increasing the period between each N application, and fertigating every second day with the other nutrients.

In conclusion, a quality transplant can be produced with no supplemental K if media K (saturated paste extract) is at least 15 $g \cdot kg^{-1}$. Phosphorus at 15 to 30 $mg \cdot L^{-1}$ P, applied every other day, is adequate for production of a quality transplant all-year-round if media P (saturated paste extract) is less than 12 $g \cdot kg^{-1}$. Nitrogen at 30 $mg \cdot L^{-1}$ applied daily during the summer or 60 $mg \cdot L^{-1}$ N applied every other day during the fall or spring can be considered

adequate for production of a quality transplant. Pretransplant N at 60 $mg \cdot L^{-1}$ in the spring or fall led to more lettuce head mass and reduced time to maturity. A quality transplant should be about 80 mm tall, fill-up a 10.9 cm^3 tray cell with roots in 28 days to facilitate ease of removal from the transplant flat, have dry root mass of no less than 25 mg, and dry shoot mass of about 100 mg to achieve a RSR of approximately 0.25. Adequate tissue levels for N, P, and K are about 17, 4, and 40 $g \cdot kg^{-1}$, respectively.

Identifying and understanding the differential growth responses of roots and shoots of lettuce transplants to N, P, and K fertilization, has provided new guidelines for the production of quality transplants. Quality lettuce transplants can be produced with lower fertilizer inputs than growers are currently using, which could lead to lower transplant production costs, and reduce the risk of polluting the environment. The fertilizer and irrigation programs for lettuce could potentially be applied to other vegetable transplants.

APPENDIX A

PHOSPHORUS EXPERIMENTS

Table A-1. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by P nutrition for Experiment 1, June/July 1993.

Sources of variation	d.f	Mean Squares[z]						
		Fresh shoot mass (mg)	Dry shoot mass (10^{-1} mg)	Fresh root mass (mg)	Dry root mass (10^{-3} mg)	Leaf area (10^{-2} cm^2)	Leaf tissue P (10^{-4} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-4})
15 Days After Sowing								
Treatment	4		117*		497			999
Replication	3		10		71			64
Error	12		190		707			424
21 Days After Sowing								
Treatment	4	120679*	2119**	630	1111	20513**		1625**
Replication	3	1882	107	1582	6108	947		382
Error	12	7448	219	551	3420	1455		254
29 Days After Sowing								
Treatment	4	328832**	7663**	1062	4819	44463**	83331**	1931**
Replication	3	16448	817	2408	14953	849	702	311
Error	12	11123	283	1273	11812	646	397	147

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-2. Analysis of variance for the influence of P nutrition on growth characteristics of lettuce transplants for Experiment 1, June/July 1993.

Sources of variation	d.f	Mean Squares[z]					
		Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-3} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-4} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf mass ratio (10^{-5})	Root mass ratio (10^{-5})
15 Days After Sowing							
Treatment	4					418	418
Replication	3					28	28
Error	12					186	186
21 Days After Sowing							
Treatment	4	383*		297**	2712**	476**	476**
Replication	3	171		22	36	114	114
Error	12	88		15	141	84	84
29 Days After Sowing							
Treatment	4	77	595**	1082**	1283**	574**	574**
Replication	3	31	42	62	39	111	111
Error	12	131	110	103	88	50	50

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-3. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by P nutrition for Experiment 2, September/October 1995.

Sources of variation	d.f	Mean Squares[z]									
		Fresh shoot mass (10 mg)	Dry shoot mass (10^{-1} mg)	Fresh root mass (mg)	Dry root mass (10^{-3} mg)	Root length (cm)	Root area (10^{-2} cm^2)	Root diameter (10^{-8} mm)	Leaf area (10^{-2} cm^2)	Pull force (10^{-7} N)	Pulling success (%)
13 Days After Sowing											
Treatment	4	2063**	208**	19	72				3760**		
Replication	3	118	34	95	156				136		
Error	12	35	6	32	237				44		
21 Days After Sowing											
Treatment	4	62616**	8780**	2975**	8438				61427**		
Replication	3	2474	705	12	143				2598		
Error	12	985	261	292	3254				808		
28 Days After Sowing											
Treatment	4	139973**	25489**	5839**	12747	2745**	3205**	100	135795**	58	2930**
Replication	3	3103	2490*	5683*	33774*	636	1948*	886**	1678	232	933
Error	12	2056	700	1066	6758	432	497	70	1171	186	450

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-4. Analysis of variance for the influence of P nutrition on growth characteristics of lettuce transplants for Experiment 2, September/October 1993.

Sources of variation	d.f.	Mean Squares[z]						
		Leaf tissue P (10^{-2} g·kg^{-1})	Root: shoot ratio (10^{-4})	Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-3} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-4})
13 Days After Sowing								
Treatment	4		172**			5870**	5958**	5593**
Replication	3		25			175	55	952
Error	12		25			59	140	917
21 Days After Sowing								
Treatment	4		309**	414*	520**	2204**	3055**	9913**
Replication	3		17	71	21	51	11	500
Error	12		16	113	89	137	101	488
28 Days After Sowing								
Treatment	4	1748**	148**	38	480**	1900**	2226**	5980**
Replication	3	50	14*	64	42	267**	300**	618*
Error	12	17	2	81	28	45	48	115

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-5. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by P and N nutrition for Experiment 3, February 1996.

Sources of variation	d.f.	Mean Squares[z]							
		Dry shoot mass (10^{-1} mg)	Dry root mass (10^{-2} mg)	Root length (cm)	Root area (cm)	Root diameter (10^{-6} mm)	Leaf area (10^{-1} cm^2)	Leaf tissue N ($g \cdot kg^{-1}$)	Leaf tissue P ($g \cdot kg^{-1}$)
		15 Days After Sowing							
P	4	554**	7				471**		
N	1	14	71**				8		
P × N	4	4	2				2		
Replication	3	213	154**				98**		
Error	27	6	11				5		
		22 Days After Sowing							
P	4	20733**	12131**				13057**		
N	1	2774**	955*				5014**		
P × N	4	285	165*				374**		
Replication	3	1750**	2718**				794**		
Error	27	146	194				61		
		28 Days After Sowing							
P	4	104619**	40746**	62000**	586**	558**	50392**	1029**	4811**
N	1	29708**	13572**	967	16	106	23496**	505**	1647**
P × N	4	2008**	656	326	8	239	1588**	1	315**
Replication	3	4197**	2172**	4839**	59**	305*	1810**	17**	302**
Error	27	297	278	308	4	95	188	1	23

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-6. Analysis of variance for the influence of P and N nutrition on growth characteristics of lettuce transplants for Experiment 3, February 1996.

Sources of variation	d.f.	Mean Squares[z]					
		Root: shoot ratio (10^{-4})	Relative growth rate (10^{-3} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-6})
15 Days After Sowing							
P	4	2466**			6350**	10609**	50740**
N	1	177*			4	258	5450**
P × N	4	4			50	49	181
Replication	3	21			564*	225	502
Error	27	24			146	97	512
22 Days After Sowing							
P	4	1802**	731**	4486**	18561**	15318**	35981**
N	1	290**	30	5445*	5728**	6228**	9981**
P × N	4	53*	11	668	509**	515**	1348**
Replication	3	30	78**	4035*	179	127	517
Error	27	14	9	964	105	70	268
28 Days After Sowing							
P	4	2923**	286**	827	14732**	15151**	63713**
N	1	925**	24	675	2556**	5674**	33040**
P × N	4	21	9	328	230	323	1252**
Replication	3	1	71	173	50	18	8
Error	27	8	82	1083	157	92	141

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-7. Analysis of variance on the effects of P nutrition during transplant production on lettuce head mass and head quality characteristics for Experiment 1, harvested 20 Dec 1995.

Source of variation	d.f.	Mean Squares[z]						
		Head mass	Firm rating	Head height	Head diameter	Stem width	Core length	Leaf tissue P
		(g)	(10^{-4})	(10^{-1} mm)	(10^{-1} mm)	(10^{-2} mm)	(10^{-1} mm)	(10^{-2} g·kg^{-1})
Treatment	4	13579**	2445**	1846**	530	2408**	3717**	1207
Replication	3	32804	1258	1478**	623	208	208	857
Error	12	1787	442	181	249	195	378	983

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table A-8. Analysis of variance for the effects of P and N nutrition during transplant production on lettuce head mass and head quality characteristics for Experiment 2, harvested 2 May 1996.

Sources of variation	d.f.	Mean Squares[z]							
		Head mass	Firm rating	Head height	Head diameter	Stem width	Core length	Leaf tissue N	Leaf tissue P
		(g)	(10^{-4})	(10^{-1} mm)	(10^{-1} mm)	(10^{-2} mm)	(10^{-1} mm)	(10^{-2} g·kg^{-1})	(10^{-3} g·kg^{-1})
P	4	11943**	979	45	360	899**	1407	948	51
N	1	6708	810	537	23	156	14	2739	441
P × N	4	1465	241	170	446	306	55	1886	105
Replication	3	493	570	650	932	45	776	748	1085**
Error	27	1952	718	301	424	116	638	1002	143

[z]F values significant at 5 % (*) or 1 % (**) levels.

APPENDIX B

POTASSIUM EXPERIMENTS

Table B-1. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by K nutrition for Experiment 1, July/August 1993.

Sources of variation	d.f.	Mean Squares[z]						
		Fresh shoot mass (mg)	Dry shoot mass (10^{-2} mg)	Fresh root mass (mg)	Dry root mass (10^{-2} mg)	Leaf area (10^{-2} cm^2)	Leaf petiole sap K (10 $mg \cdot L^{-1}$)	Leaf tissue K (10^{-2} $g \cdot kg^{-1}$)
				15 Days After Sowing				
Treatment	4	567	117	31	12	86		
Replication	3	1024*	335*	70	14	169*		
Error	12	250	93	60	13	34		
				21 Days After Sowing				
Treatment	4	894	223	1198	398	209	7325*	
Replication	3	5210	1811	757	155	779	22733**	
Error	12	3128	750	814	255	348	2025	
				28 Days After Sowing				
Treatment	4	12156	4868	1126	597	1265	27425**	4083**
Replication	3	3652	3050	1343	1165	821	5250	2793**
Error	12	12003	2614	717	179	1222	2125	242

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table B-2. Analysis of variance for the influence of K nutrition on growth characteristics of lettuce transplants for Experiment 1, July/August 1993.

Sources of variation	d.f.	Mean Squares[z]					
		Root: shoot ratio (10^{-5})	Relative growth rate (10^{-5} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-6} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-6})
		15 Days After Sowing					
Treatment	4	146			2314	2050*	383
Replication	3	164			150	286	422
Error	12	335			1098	615	889
		21 Days After Sowing					
Treatment	4	174	1655	1194	2499	2076	641
Replication	3	80	1295	1053	1013	1093	307
Error	12	212	512	429	990	1148	770
		28 Days After Sowing					
Treatment	4	21	560	192	646	329	79
Replication	3	132	659	244	128	485	529*
Error	12	38	333	137	413	393	150

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table B-3. Sources of variation in the analysis of variance for the effects of light, potassium, and media on root and shoot characteristics of lettuce transplants for Experiment 2, February 1994.

Treatments[z]	Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (mg)	Leaf area (cm^2)	Leaf petiole sap K ($mg \cdot L^{-1}$)	Leaf tissue K ($g \cdot kg^{-1}$)
				23 Days After Sowing			
L_1 K_1 M_1	1036	62.4	226	11.2	39.1	2000	
L_1 K_1 M_2	1037	52.5	192	8.5	32.2	110	
L_1 K_2 M_1	970	60.5	219	11.0	34.3	2367	
L_1 K_2 M_2	1155	65.5	199	10.4	41.6	1067	
L_2 K_1 M_1	974	83.3	288	17.1	34.6	1900	
L_2 K_1 M_2	961	57.0	205	15.4	30.0	92	
L_2 K_2 M_1	1054	83.9	301	16.5	37.0	2033	
L_2 K_2 M_2	1153	82.2	252	15.1	41.2	903	
Source							
Light (L)	NS	**	NS	NS	NS	NS	
Potas (K)	*	**	NS	NS	**	**	
Media (M)	NS	**	**	NS	NS	**	
L × K	NS	NS	NS	NS	NS	NS	
L × M	NS	*	NS	NS	NS	NS	
K × M	NS	**	NS	NS	**	**	
L × K × M	NS	NS	NS	NS	NS	NS	
				30 Days After Sowing			
L_1 K_1 M_1	1504	113.1	325	24.6	54.3	2033	33.7
L_1 K_1 M_2	1366	83.8	218	16.2	40.6	85	3.0
L_1 K_2 M_1	1398	108.1	370	29.1	50.3	2900	41.9
L_1 K_2 M_2	1784	123.6	359	25.3	64.7	1100	19.0
L_2 K_1 M_1	1408	134.7	430	35.1	59.7	1800	26.8
L_2 K_1 M_2	1291	102.4	259	19.2	36.3	71	2.4
L_2 K_2 M_1	1446	133.9	470	38.0	50.6	2367	33.5
L_2 K_2 M_2	1904	160.4	395	32.5	65.0	1100	15.5
Source							
Light (L)	NS	*	NS	*	NS	*	NS
Potas (K)	**	**	**	**	**	**	**
Media (M)	**	NS	**	**	NS	**	**
L × K	NS	NS	NS	NS	NS	NS	NS
L × M	NS	NS	*	*	NS	*	*
K × M	**	**	**	**	**	NS	**
L × K × M	NS	NS	NS	NS	NS	NS	NS

[z]L_1 = photoperiod extension to 16 h; L_2 = supplementary light for 16 h; K_1 = 0 $mg \cdot L^{-1}$ K; K_2 = 60 $mg \cdot L^{-1}$ K; M_1 = peat+vermiculite mix; M_2 = peat+rockwool mix.
NS, *, **Nonsignificant (NS) or significant at 5 % (*), 1 % (**) levels.

Table B-4. Sources of variation in the analysis of variance for the effects of light, potassium, and media on growth characteristics of lettuce transplants for Experiment 2, February 1994.

Treatments[z]	Root: shoot ratio	Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate ($mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio ($cm^2 \cdot mg^{-1}$)	Leaf mass ratio	Root mass ratio
			23 Days After Sowing				
L_1 K_1 M_1	0.18			0.63	0.53	0.85	0.15
L_1 K_1 M_2	0.16			0.61	0.53	0.86	0.14
L_1 K_2 M_1	0.18			0.57	0.48	0.85	0.15
L_1 K_2 M_2	0.16			0.64	0.55	0.87	0.13
L_2 K_1 M_1	0.20			0.42	0.35	0.83	0.17
L_2 K_1 M_2	0.28			0.53	0.42	0.79	0.21
L_2 K_2 M_1	0.19			0.44	0.37	0.84	0.16
L_2 K_2 M_2	0.18			0.50	0.42	0.85	0.15
Source							
Light (L)	NS			*	*	NS	NS
Potas (K)	NS			NS	NS	NS	NS
Media (M)	NS			**	**	NS	NS
L × K	NS			NS	NS	NS	NS
L × M	NS			*	NS	NS	NS
K × M	NS			NS	NS	NS	NS
L × K × M	NS			**	NS	NS	NS
			30 Days After Sowing				
L_1 K_1 M_1	0.22	0.63	1.39	0.48	0.39	0.82	0.18
L_1 K_1 M_2	0.19	0.50	1.08	0.48	0.41	0.84	0.16
L_1 K_2 M_1	0.27	0.65	1.57	0.48	0.37	0.79	0.21
L_1 K_2 M_2	0.20	0.68	1.40	0.52	0.43	0.83	0.17
L_2 K_1 M_1	0.26	0.53	1.66	0.37	0.29	0.79	0.21
L_2 K_1 M_2	0.19	0.51	1.50	0.36	0.31	0.84	0.16
L_2 K_2 M_1	0.28	0.54	1.69	0.38	0.30	0.78	0.22
L_2 K_2 M_2	0.20	0.68	1.83	0.41	0.34	0.83	0.17
Source							
Light (L)	NS	NS	NS	*	*	NS	NS
Potas (K)	*	*	NS	NS	NS	*	*
Media (M)	**	NS	NS	NS	*	**	**
L × K	NS	NS	NS	NS	NS	NS	NS
L × M	NS	NS	NS	NS	NS	NS	NS
K × M	NS	*	NS	NS	NS	NS	NS
L × K × M	NS	NS	NS	NS	NS	NS	NS

[z]L_1 = photoperiod extension to 16 h; L_2 = supplementary light for 16 h; K_1 = 0 $mg \cdot L^{-1}$ K; K_2 = 60 $mg \cdot L^{-1}$ K; M_1 = peat+vermiculite mix; M_2 = peat+rockwool mix.

NS, *, **Nonsignificant (NS) or significant at 5 % (*), 1 % (**) levels.

Table B-5. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by light, potassium, and media for Experiment 2, February 1994.

Sources of variation[y]	d.f.	Mean Squares[z]						
		Fresh shoot mass (mg)	Dry shoot mass (mg)	Fresh root mass (mg)	Dry root mass (10^{-1} mg)	Leaf area (10^{-4} cm^2)	Leaf petiole sap K (10^2 $mg \cdot L^{-1}$)	Leaf tissue K (10^{-1} $g \cdot kg^{-1}$)
23 Days After Sowing								
L	1	1121	1607**	16631	19918	73793	1415	
K	1	39327*	513**	1369	28	1242696**	19295**	
M	1	27478	403**	12856**	1559	2	140837**	
L × K	1	18193	82	1418	265	297928	539	
L × M	1	3739	202	2228	2	2680	239	
K × M	1	32980	588	854	212	1992039**	6033**	
L × K × M	1	2007	36	155	126	107951	29	
Reps (L)	4	13291	79	2691*	3427	119236	709	
Error	12	7866	35	6641	1318	81077	266	
30 Days After Sowing								
L	1	1	3950*	29589	32960*	254781	2289*	1399
K	1	346556**	3171**	49049**	33436**	9266814**	45344**	7221**
M	1	130075**	143	49724**	42219**	12586	170556**	34521**
L × K	1	42904	188	41	242	345312	305	75
L × M	1	3248	23	6219*	3188*	523	2121*	482*
K × M	1	451141**	4030**	13833**	8311*	11655513**	1398	764**
L × K × M	1	961	74	1	1276	129	371	7
Reps (L)	4	31778	315	5449**	2014	379191*	273	272
Error	12	14290	135	907	389	104994	304	60

[z]F values significant at 5 % (*) or 1 % (**) levels.

[y]L = photoperiod extension to 16 h or supplementary light for 16 h; K = 0 or 60 $mg \cdot L^{-1}$ K; M = peat+vermiculite or peat+rockwool mix.

Table B-6. Analysis of variance for the influence of light, potassium, and media on growth characteristics of lettuce transplants for Experiment 2, February 1994.

Sources of variation[y]	d.f.	Mean Squares[z]					
		Root:shoot ratio (10^{-5})	Relative growth rate (10^{-6} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-6})
23 Days After Sowing							
L	1	1172			11582*	10656*	5371
K	1	405			63	0	1636
M	1	17			1803**	1274**	8
L × K	1	396			24	108	1529
L × M	1	418			541*	110	1960
K × M	1	355			33	134	1348
L × K × M	1	216			609**	282	724
Reps (L)	4	391			585**	729**	1921
Error	12	410			66	89	1839
30 Days After Sowing							
L	1	95	13617	5846	7512*	5332*	383
K	1	421*	56142*	2738	290	66	1774*
M	1	2213**	86	959	190	584*	9529**
L × K	1	32	206	91	7	24	141
L × M	1	123	19201	772	30	14	513
K × M	1	118	39749*	720	196	228	425
L × K × M	1	43	4	86	2	12	186
Reps (L)	4	50	12009	1418	510	336	198
Error	12	54	8378	10319	205	104	228

[z]F values significant at 5 % (*) or 1 % (**) levels.

[y]L = photoperiod extension to 16 h or supplementary light for 16 h; K = 0 or 60 mg·L^{-1} K; M = peat+vermiculite or peat+rockwool mix.

Table B-7. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by K and N nutrition for Experiment 3, February 1996.

Sources of variation	d.f.	Mean Squares[z]					
		Dry shoot mass (10^{-2} mg)	Dry root mass (10^{-5} mg)	Leaf area (10^{-2} cm^2)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)	Leaf tissue K (10^{-1} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-5})
		15 Days After Sowing					
K	4	48	15954	16			179
N	1	581**	9	442**			756**
K × N	4	10	9974	17			107
Replication	3	1697**	222305**	1021**			50
Error	27	59	7861	24			72
		22 Days After Sowing					
K	4	2570**	224065	358			311**
N	1	74650**	6240004**	83423**			12550**
K × N	4	902	213894	973			44
Replication	3	34528**	1584516**	13031**			107
Error	27	351	157945	792			58
		28 Days After Sowing					
K	4	5896	239933	1631	242	3983**	36
N	1	584286**	13884939**	545400**	74184**	283	12810**
K × N	4	4348	340434	4836*	162	508	43
Replication	3	44827**	5741831**	12810**	466**	534	86
Error	27	4921	380136	1443	96	281	48

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table B-8. Analysis of variance for the influence of K and N nutrition on growth characteristics of lettuce transplants for Experiment 3, February 1996.

Sources of variation	d.f.	Mean Squares[z]					
		Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-6} cm^2·mg^{-1})	Leaf area ratio (10^{-5} cm^2·mg^{-1})	Leaf mass ratio (10^{-6})	Root mass ratio (10^{-6})
				15 Days After Sowing			
K	4			972	72	577	577
N	1			552	308*	2355**	2355**
K × N	4			1810	170*	339	339
Replication	3			302	7	162	162
Error	27			1160	60	238	238
				22 Days After Sowing			
K	4	63	1106	11025	425	1128**	1128**
N	1	240	6733**	48553**	10481**	46694**	46694**
K × N	4	77	234	2649	180	152	152
Replication	3	121	616	3570	121	409	409
Error	27	59	499	4096	238	212	212
				28 Days After Sowing			
K	4	19	95	878	52	139	139
N	1	421*	2643**	68503**	12138**	48441**	48441**
K × N	4	57	392	3209*	224**	152	152
Replication	3	285*	726	3394*	318**	350	350
Error	27	68	303	930	53	178	178

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table B-9. Analysis of variance for the effects of K and N nutrition during transplant production on lettuce head mass and head quality characteristics, harvested 3 May 1996.

Sources of variation	d.f.	Mean Squares[z]							
		Head mass	Firm rating	Head height	Head diameter	Stem width	Core length	Leaf tissue N	Leaf tissue K
		(g)	(10^{-5})	(10^{-1} mm)	(mm)	(10^{-3} mm)	(10^{-2} mm)	(10^{-2} g·kg^{-1})	(10^{-1} g·kg^{-1})
K	4	1211	125	390	58.5	759	457	1600	1870*
N	1	116	100	23	102.8	306	837	314	23
K × N	4	1519	225	102	4.7	663	36	1406	365
Replication	3	1560	1133	2349**	51.3	6928**	881	308	1160
Error	27	849	411	279	41.5	1523	552	685	500

[z]F values significant at 5 % (*) or 1 % (**) levels.

APPENDIX C

NITROGEN EXPERIMENTS

Table C-1. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 1, September 1993.

Sources of variation	d.f.	Mean Squares[z]						
		Fresh shoot mass (10 mg)	Dry shoot mass (10^{-2} mg)	Fresh root mass (mg)	Dry root mass (10^{-4} mg)	Leaf area (10^{-2} cm^2)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-4})
15 Days After Sowing								
Treatment	4	1762**	1335	115**	775	3440**		792*
Replication	3	26	15	36	419	37		29
Error	12	35	428	12	669	50		215
22 Days After Sowing								
Treatment	4	15925**	43426**	3926**	90980**	26787**		2026**
Replication	3	12	134	46	2974	85		81
Error	12	43	122	42	6255	62		91
28 Days After Sowing								
Treatment	4	27469**	144203**	16171**	746016**	48593**	5709**	1365**
Replication	3	114	2258	535	42560*	277	83	11
Error	12	111	1390	139	8147	226	122	5

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-2. Analysis of variance for the influence of N nutrition on growth characteristics of lettuce transplants for Experiment 1, September 1993.

Sources of variation	d.f.	Mean Squares[z] Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-3} cm^{2}·mg^{-1})	Leaf area ratio (cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-5})
			15 Days After Sowing			
Treatment	4			472	31229**	1966*
Replication	3			109	2663	43
Error	12			215	5257	56
			22 Days After Sowing			
Treatment	4	5059**	584	6997	126989**	4232**
Replication	3	327	313	1579	3500	79
Error	12	881	1501	2332	6556	126
			28 Days After Sowing			
Treatment	4	179	7584**	70**	3009**	2661**
Replication	3	161	1406	11	22	20
Error	12	106	753	6	36	10

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-3. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 2, November/December 1993.

Sources of variation	d.f.	Mean Squares[z]						
		Fresh shoot mass (10 mg)	Dry shoot mass (10^{-2} mg)	Fresh root mass (mg)	Dry root mass (10^{-3} mg)	Leaf area (10^{-3} cm^2)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-5})
		15 Days After Sowing						
Treatment	4	3281**	4233**	440**	2885**	41305**		320
Replication	3	18	40	72	260	196		380
Error	12	14	87	68	378	300		623
		21 Days After Sowing						
Treatment	4	15387**	57675**	7850**	27169**	188786**		4139**
Replication	3	97	152	170	1110	2998*		271
Error	12	58	487	97	481	568		126
		28 Days After Sowing						
Treatment	4	43762**	195044**	21293**	73582**	531665**	7191**	7328**
Replication	3	117	5553	1146	11944**	2995	399*	1036
Error	12	207	3506	451	2021	2614	73	629

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-4. Analysis of variance for the influence of N nutrition on growth characteristics of lettuce transplants for Experiment 2, November/December 1993.

Sources of variation	d.f.	Mean Squares[z]				
		Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-3} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-5})
			15 Days After Sowing			
Treatment	4			7952**	4307**	189
Replication	3			695	213	147
Error	12			423	471	314
			21 Days After Sowing			
Treatment	4	242	2442**	4233**	3436**	1071**
Replication	3	140	491	650**	435**	64
Error	12	379	311	46	24	34
			28 Days After Sowing			
Treatment	4	1192**	1326**	3801**	3484**	1734**
Replication	3	153	667**	797*	688*	211
Error	12	50	88	139	78	108

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-5. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 3, August 1994.

Sources of variation	d.f.	Mean Squares[z]						
		Fresh shoot mass (mg)	Dry shoot mass (10^{-2} mg)	Fresh root mass (mg)	Dry root mass (10^{-2} mg)	Leaf area (10^{-2} cm^2)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-6})
15 Days After Sowing								
Treatment	4	38478**	9047**	763	291**	6961**		79699**
Replication	3	189	382*	440	30	52		1747
Error	12	162	85	391	17	35		1755
22 Days After Sowing								
Treatment	4	185061**	81691**	7983**	3879**	31641**		94222**
Replication	3	186	609	258	204	149		1653
Error	12	438	358	533	61	82		1874
29 Days After Sowing								
Treatment	4	509609**	256742**	40850**	17540**	78402**	6966**	72398**
Replication	3	6493	4737	2720*	1452	841	67	1249
Error	12	5738	3689	572	655	629	40	2135

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-6. Analysis of variance for the influence of N nutrition on growth characteristics of lettuce transplants for Experiment 3, August 1994.

Sources of variation	d.f.	Mean Squares[z] Relative growth rate (10^{-5} mg·mg^{-1}·wk^{-1})	Net assimilation rate (mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-6})
			15 Days After Sowing			
Treatment	4			10805**	8335**	16577**
Replication	3			307	135	390
Error	12			137	65	396
			22 Days After Sowing			
Treatment	4	17215**	444	5789**	4957**	20185**
Replication	3	60	147	57	59	442
Error	12	1493	229	71	34	400
			29 Days After Sowing			
Treatment	4	6236	482	5776**	4397**	15767**
Replication	3	1973	288	31	32	397
Error	12	2005	265	43	44	528

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-7. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition for Experiment 4, September/October 1994.

Sources of variation	d.f.	Mean Squares[z]							
		Fresh shoot mass (10 mg)	Dry shoot mass (10^{-1} mg)	Fresh root mass (mg)	Dry root mass (10^{-2} mg)	Leaf area (10^{-2} cm^2)	Plant height (mm)	Stem diameter (10^{-4} mm)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)
		15 Days After Sowing							
Treatment	4	5928**	1398**	2079*	781**	10353**	1329**		
Replication	3	43	2	69	55	99	11		
Error	12	45	13	457	55	78	7		
		22 Days After Sowing							
Treatment	4	20519**	6025**	10387**	4113**	30741**	1425**		
Replication	3	291	243	209	170	269	7		
Error	12	215	165	144	144	141	5		
		29 Days After Sowing							
Treatment	4	48666**	17839**	24321**	12622**	77863**	2225**	5731**	9610**
Replication	3	733	873	636*	506	1077	20	206	177
Error	12	755	315	139	204	814	21	241	152

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-8. Analysis of variance for the influence of N nutrition on growth characteristics of lettuce transplants for Experiment 4, September/October 1994.

Sources of variation	d.f.	Mean Squares[z]					
		Root:shoot ratio (10^{-5})	Relative growth rate (10^{-5} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-3} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-5})
15 Days After Sowing							
Treatment	4	3571**			9386**	7235**	945**
Replication	3	200			484	320	49
Error	12	605			168	125	141
22 Days After Sowing							
Treatment	4	4886**	239	3749**	9200**	6497**	1106**
Replication	3	34	1847	118	81	32	6
Error	12	202	1591	106	299	134	40
29 Days After Sowing							
Treatment	4	4439**	2842*	864**	8519**	5980**	1038**
Replication	3	163	2122	210	189	74	45
Error	12	140	825	92	98	60	32

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table C-9. Effects of N nutrition during transplant production on lettuce head mass and head quality characteristics, harvested 6 and 12 December 1994.

Nitrogen applied ($mg \cdot L^{-1}$)	Head mass (g)	Firm rating[z] (1-5)	Head height (mm)	Head diameter (mm)	Stem width (mm)	Core length (mm)
			53 Days After Transplanting			
15	556	4.5	104	115	21	32
30	577	4.7	109	119	22	34
45	579	4.8	107	116	22	35
60	577	4.8	106	115	21	37
	NS	NS	NS	NS	NS	NS
			59 Days After Transplanting			
15	641	4.8	116	126	22	41
30	606	4.9	120	121	22	45
45	613	4.8	121	123	22	48
60	664	4.7	122	129	23	49
	NS	NS	NS	Q*	NS	L**

[z]Lettuce head firmness on a scale of 1 = loose, 5 = compact.
Linear (L) or quadratic (Q) effects significant at P = 0.05 (*), 0.01 (**), or nonsignificant (NS).

Table C-10. Analysis of variance for the effects of N nutrition during transplant production on lettuce head mass and head quality characteristics, harvested 9 December 1994.

Sources of variation	d.f.	Mean Squares[z]						
		Head mass	Firm rating	Head height	Head diameter	Stem width	Core length	Leaf tissue N
		(g)	(10^{-5})	(10^{-2} mm)	(10^{-2} mm)	(10^{-3} mm)	(10^{-2} mm)	(10^{-3} g·kg^{-1})
Treatment	3	8075	750	6004**	1648	3208	3086*	1225
Replication	3	8057	419	2315	2225	2209	2052	1802
Error	9	2741	1139	774	797	1285	758	4732

[z]F values significant at 5 % (*) or 1 % (**) levels.

APPENDIX D

NITROGEN AND IRRIGATION EXPERIMENTS

Table D-1. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by irrigation frequency for Experiment 1, June/July 1994.

Sources of variation	d.f	Mean Squares[z] Fresh shoot mass (mg)	Dry shoot mass (10^{-2} mg)	Fresh root mass (mg)	Dry root mass (10^{-3} mg)	Leaf area (10^{-2} cm^2)	Leaf tissue N (10^{-2} $g \cdot kg^{-1}$)	Leaf tissue P (10^{-3} $g \cdot kg^{-1}$)	Leaf tissue K ($g \cdot kg^{-1}$)
					15 Days After Sowing				
Treatment	3	4121**	1483**	1863**	4197**	756**			
Replication	3	34	99	37	126	1			
Error	9	228	67	42	288	25			
					22 Days After Sowing				
Treatment	3	107735**	18897**	2593**	1092	15109**			
Replication	3	1683	1082	336	581	277			
Error	9	2524	475	322	996	203			
					29 Days After Sowing				
Treatment	3	535467**	85198**	6361	12028*	59971**	7575**	1626**	151.6**
Replication	3	7465*	2940*	1374	3343	618	445*	32	11.5*
Error	9	1851	714	1854	3027	169	103	21	2.4

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table D-2. Analysis of variance for the influence of irrigation frequency on growth characteristics of lettuce transplants for Experiment 1, June/July 1994.

Sources of variation	d.f.	Mean Squares[z]					
		Root: shoot ratio (10^{-6})	Relative growth rate (10^{-5} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-6})
		15 Days After Sowing					
Treatment	3	2099			10334**	5563**	617
Replication	3	1518			789	250	386
Error	9	4771			403	55	1129
		22 Days After Sowing					
Treatment	3	20466**	32149**	770	4003**	3175**	548**
Replication	3	2635	1949	498	40	31	78
Error	9	913	633	493	111	54	26
		29 Days After Sowing					
Treatment	3	21124**	4445**	6458**	2143**	2270**	653**
Replication	3	1421	92	95	22	25	46
Error	9	521	385	528	42	26	17

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table D-3. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 2, February/March 1995.

Sources of variation[y]	d.f.	Mean Squares[z]						
		Dry shoot mass (10^{-1} mg)	Dry root mass (10^{-1} mg)	Leaf area (10^{-1} cm^2)	Pull force (10^{-7} N)	Pulling success (%)	Leaf tissue N ($g \cdot kg^{-1}$)	Root: shoot ratio (10^{-4})
				13 Days After Sowing				
N	4	1548**	86**	1481**				8192**
F	3	394**	21**	485**				297
N × F	12	36*	3	33**				151
Replication	3	10	58**	8				1533**
Error	57	17	2	5				186
				21 Days After Sowing				
N	4	62156**	5629**	24153**				13092**
F	3	33785**	2020**	11162**				643**
N × F	12	2534**	158**	1122**				114
Replication	3	719	175**	119				888**
Error	57	309	34	104				102
				28 Days After Sowing				
N	4	364230**	17572**	119150**	9949**	17718**	3392**	16163**
F	3	212456**	7647**	52433**	4454**	1205**	9	710**
N × F	12	19908**	524**	5784**	466**	334	33**	14
Replication	3	1965	374	98	166	1245**	151**	355**
Error	57	2197	169	449	110	0.79	13	45

[z]F values significant at 5 % (*) or 1 % (**) levels.
[y]N = nitrogen; F = fertigation frequency.

Table D-4. Analysis of variance for the influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 2, February/March 1995.

Sources of variation[y]	d.f.	Mean Squares[z]					
		Relative growth rate ($mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate (10^{-3} $mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area ($cm^2 \cdot mg^{-1}$)	Leaf area ratio (10^{-5} $cm^2 \cdot mg^{-1}$)	Leaf mass ratio (10^{-5})	Root mass ratio (10^{-5})
			13 Days After Sowing				
N	4				64415**	12800**	12800**
F	3				5905**	596	596
N × F	12				1252**	209	209
Replication	3				4261**	3238**	3238**
Error	57				385	283	283
			21 Days After Sowing				
N	4	36416**	2086**	290**	26551**	16898**	16898**
F	3	5731**	3035**	17**	1487**	1512**	1512**
N × F	12	358	110	1	74	154*	154*
Replication	3	2247**	453	12**	95	1474**	1474**
Error	57	307	240	1	47	75	75
			28 Days After Sowing				
N	4	1798**	20263**	338**	32544**	25510**	25510**
F	3	341*	482	11**	484**	1679**	1679**
N × F	12	116	314	1	49	66	66
Replication	3	227	730*	5**	67	716**	716**
Error	57	112	253	1	44	60	60

[z]F values significant at 5 % (*) or 1 % (**) levels.

[y]N = nitrogen; F = fertigation frequency.

Table D-5. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 3, July 1995.

Sources of variation[y]	d.f.	Mean Squares[z]						
		Dry shoot mass (mg)	Dry root mass (10^{-1} mg)	Leaf area (10^{-1} cm^2)	Pull force (10^{-7} N)	Pulling success (%)	Leaf tissue N (10^{-1} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-4})
				13 Days After Sowing				
N	4	657**	206**	4116**				9859**
F	3	250**	38**	1433**				752**
N × F	12	18**	12	102**				172**
Replication	3	8*	89**	130**				740**
Error	57	3	7	9				61
				21 Days After Sowing				
N	4	9496**	3747**	47933**				13379**
F	3	3579**	781**	15122**				305**
N × F	12	368**	189**	1725**				129**
Replication	3	188**	673**	590**				1104**
Error	57	33	65	93				46
				28 Days After Sowing				
N	4	37122**	13982**	129255**	11507**	13178**	15949**	16299**
F	3	17173**	2579**	42543**	1140**	640	701**	58
N × F	12	2318**	341	5681**	244	366	143**	71
Replication	3	827**	1778**	830**	1035**	2679**	112*	246*
Error	57	138	262	197	175	578	37	75

[z]F values significant at 5 % (*) or 1 % (**) levels.
[y]N = nitrogen; F = fertigation frequency.

Table D-6. Analysis of variance for the influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 3, July 1995.

Sources of variation[y]	d.f.	Mean Squares[z]				
		Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-3} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-4})
			13 Days After Sowing			
N	4			64885**	53608**	1927**
F	3			1166	3046**	225**
N × F	12			390	268	37**
Replication	3			3124**	4423**	220**
Error	57			636	277	14
			21 Days After Sowing			
N	4	17978**	3078**	50789**	46820**	2290**
F	3	1890**	717*	246*	1064**	122**
N × F	12	204	73	102	89	28**
Replication	3	592	77	134	527**	273**
Error	57	231	232	67	47	7
			28 Days After Sowing			
N	4	3385**	7301**	27992**	32908**	2839**
F	3	646*	235	109	44	39**
N × F	12	393*	320	253	93	13
Replication	3	346	338	943**	796**	68**
Error	57	159	422	148	95	9

[z]F values significant at 5 % (*) or 1 % (**) levels.

[y]N = nitrogen; F = fertigation frequency.

Table D-7. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by N nutrition and fertigation frequency for Experiment 4, September/October 1995.

Sources of variation[y]	d.f.	Mean Squares[z]						
		Dry shoot mass (10^{-1} mg)	Dry root mass (10^{-2} mg)	Leaf area (10^{-1} cm^2)	Pull force (10^{-7} N)	Pulling success (%)	Leaf tissue N (10^{-1} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-4})
13 Days After Sowing								
N	4	3033**	1278**	3640**				7721**
F	3	213**	29	207**				499**
N × F	12	21**	18	15**				104*
Replication	3	81**	143**	34**				64
Error	57	6	11	4				48
21 Days After Sowing								
N	4	77619**	35273**	47341**				9036**
F	3	8765**	387	5087**				621**
N × F	12	958**	222	591**				19
Replication	3	923**	2890**	163**				148*
Error	57	117	156	36				37
28 Days After Sowing								
N	4	379335**	99054**	168770**	5976**	26621**	7885**	12746**
F	3	56226**	4178**	17436**	358**	207	142*	191**
N × F	12	8306**	1019	2172**	71	65	95*	19
Replication	3	1753*	9821**	213	24	60	111	120*
Error	57	537	559	89	57	152	42	32

[z]F values significant at 5 % (*) or 1 % (**) levels.
[y]N = nitrogen; F = fertigation frequency.

Table D-8. Analysis of variance for the influence of N nutrition and fertigation frequency on growth characteristics of lettuce transplants for Experiment 4, September/October 1995.

Sources of variation[y]	d.f.	Mean Squares[z]				
		Relative growth rate (10^{-4} mg·mg^{-1}·wk^{-1})	Net assimilation rate (10^{-4} mg·cm^{-2}·wk^{-1})	Specific leaf area (10^{-5} cm^{2}·mg^{-1})	Leaf area ratio (10^{-5} cm^{2}·mg^{-1})	Leaf and root mass ratios (10^{-5})
13 Days After Sowing						
N	4			112815**	92707**	14672**
F	3			1624**	2182**	1379**
N × F	12			262	171	183**
Replication	3			1393**	1256**	99
Error	57			171	95	60
21 Days After Sowing						
N	4	29553**	2072	54044**	51985**	17848**
F	3	1093**	4088**	551**	1482**	1568**
N × F	12	193*	2986**	350**	206**	48
Replication	3	84	2607	734**	894**	302**
Error	57	100	956	102	51	51
28 Days After Sowing						
N	4	1472**	92264**	38141**	45113**	26944**
F	3	218	717	297	203	679**
N × F	12	140	1233	379*	170	77
Replication	3	213	5393	542*	526**	346**
Error	57	101	1996	170	122	42

[z]F values significant at 5 % (*) or 1 % (**) levels.

[y]N = nitrogen; F = fertigation frequency.

Table D-9. Analysis of variance for root and shoot characteristics of lettuce transplants as affected by timing of N application for Experiment 5, April 1996.

Sources of variation	d.f.	Mean Squares[z]									
		Fresh shoot mass (10^2 mg)	Dry shoot mass (mg)	Fresh root mass (10 mg)	Dry root mass (mg)	Root length (10 cm)	Root area (cm^2)	Root diameter (10^{-6} mm)	Leaf area (cm^2)	Plant height (10^{-1} mm)	Pull force (10^{-7} N)	Pulling success (%)
22 Days After Sowing												
Treatment	4	8245**	4202**	5844**	380.2**					21434**		
Replication	3	29	47*	42	4.2*					7		
Error	12	13	10	26	1.2					57		
28 Days After Sowing												
Treatment	4	19284**	10313**	14611**	1089.3**	6918**	791**	2734**	1753**	29929**	3096**	10830**
Replication	3	28	61*	201*	13.0*	183**	10	148*	2	102	229*	27
Error	12	49	14	57	3.6	25	2	38	3	90	42	43

[z]F values significant at 5 % (*) or 1 % (**) levels.

Table D-10. Analysis of variance for the influence of timing of N application on growth characteristics of lettuce transplants for Experiment 5, April 1996.

Sources of variation	d.f.	Mean Squares[z]							
		Leaf sap NO_3-N ($mg \cdot L^{-1}$)	Leaf tissue N (10^{-1} $g \cdot kg^{-1}$)	Root: shoot ratio (10^{-5})	Relative growth rate (10^{-4} $mg \cdot mg^{-1} \cdot wk^{-1}$)	Net assimilation rate (10^{-3} $mg \cdot cm^{-2} \cdot wk^{-1}$)	Specific leaf area (10^{-4} $cm^2 \cdot mg^{-1}$)	Leaf area ratio (10^{-5} $cm^2 \cdot mg^{-1}$)	Leaf and root mass ratios (10^{-5})
22 Days After Sowing									
Treatment	4			26637**			842**	5208**	4012**
Reps	3			317			23*	88*	40
Error	12			156			4	23	13
28 Days After Sowing									
Treatment[y]	4	29979**	2248**	30025**	7449**	2227**	914**	6173**	4189**
Reps	3	3992	4	94	241	695	5	27	8
Error	12	2095	4	121	71	507	2	11	14

[z]F values significant at 5 % (*) or 1 % (**) levels.
[y]Only 4 treatments for leaf sap nitrate.

LIST OF REFERENCES

Aloni, B., T. Pashkar, L. Karni, and J. Daie. 1991. Nitrogen supply influences carbohydrate partitioning of pepper seedlings and transplant development. J. Amer. Soc. Hort. Sci. 116:995-999.

Anon. 1986. Beating bacterial leaf spot in Bushnell. Amer. Veg. Grower 34:28+.

Anon. 1995. Florida agricultural statistics: Vegetable summary 1993-1994. Florida Agricultural Statistics Service, Orlando.

Basoccu, L. and S. Nicola. 1990. Light conditions, timing fertilization and water availability influence on nursery development of lettuce seedlings and their effect on field productivity. Acta Hortic. 287:399-404.

Boivin, C., M. J. Trudel, and A. Gosselin. 1986. Influence du niveau d'irradiance d'appoint (HPS) en pépinière sur la croissance d'une cluture de tomate de serre. Can. J. Plant Sci. 66:961-970.

Cantliffe, D.J. 1990. Performance of crisphead lettuce cultivars on plastic-mulched, drip-irrigated sandy soils in Florida. Belle Glade EREC Research Report EV-1990-7:48-56.

Chipman, E.W. 1961. The effect of seeding and plant topping on the production of early and total yields of ripe tomatoes. Proc. Amer. Soc. Hort. Sci. 77:483-486.

Cliffe, D.O. 1989. Production and scheduling of lettuce transplants for commercial crop production. Acta Hortic. 247:49-51.

Costigan, P.A. and G.P. Mead. 1987. The requirements of cabbage and lettuce seedlings for potassium in the presence and absence of sodium. J. Plant Nutr. 10:385-401.

Craker, L.E. and Seibert, M. 1983. Light and the development of Grand Rapids lettuce. Can. J. Plant Sci. 63:277-281.

Decoteau, D.R. and H.H. Friend. 1991. Growth and subsequent yield of tomatoes following end-of-day light treatment of transplants. HortScience 25:1528-1530.

Dennis, D.J. and W.M. Dullforce. 1975. The response of the heated glasshouse lettuce crop to *in situ* supplements of low illuminance flourescent light. Acta hortic. 51:185-201.

Dubik, S.P., D.T. Krizek, and D.P. Stimart. 1990. Influence of root zone restriction on mineral element concentration, water potential, chlorophyll concentration, and partitioning of assimilate in spreading euonymus (*E. kiautschovica* Loes. 'Sieboldiana'). J. Plant Nutr. 13:677-699.

Dubik, S.P., D.T. Krizek, D.P. Stimart, and M.S. McIntosh. 1992. Growth analysis of spreading euonymus subjected to root restriction. J. Plant Nutr. 15:469-486.

Dufault, R.J. 1985. Relationship among nitrogen, phosphorus, and potassium fertility regimes on celery transplant growth. HortScience 20:1104-1106.

Dufault, R.J. and L. Waters, Jr. 1985. Container size influences broccoli and cauliflower transplant growth but not yield. HortScience 20:682-684.

Dufault, R.J. and R.R. Melton. 1990. Cyclic cold stresses before transplanting influence tomato seedling growth, but not fruit earliness, fresh market yield, or quality. J. Amer. Soc. Hort. Sci. 115:559-563.

Dufault, R.J. and J.R. Schultheis. 1994. Bell pepper seedling growth and yield following pretransplant nutritional conditioning. HortScience 29:999-1001.

Dullforce, W.M. 1971. The growth of winter glasshouse lettuce with artificial light. Acta Hortic. 22:199-210.

Garton, R.W. and I.E. Widders. 1990. Nitrogen and phosphorus preconditioning of small-plug seedlings influence processing tomato productivity. HortScience 25:655-657.

Guzman, V.L. 1990. Effect of high temperatures during the seedling stage on yield and quality of crisphead lettuce. Belle Glade EREC Research Report EV-1990-7:101-108.

Guzman, V.L. 1993. Effect of rootball volume and three soluble fertilizer formulas applied at the seedling stage on yields and quality of transplanted crisphead lettuce. Belle Glade EREC Research Report EV-1993-2:11-17.

Guzman, V.L., C.A. Sanchez, and R.T. Nagata. 1989. A comparison of transplanted and direct-seeded lettuce at various levels of soil fertility. Soil Crop Sci. Soc. Fla Proc. 48:26-28.

Hall, M.R. 1989. Cell size of seedling containers influences early vine growth and yield of transplanted watermelon. HortScience 24:771-773.

Hanlon, E.A., J.G. Gonzalez, and J.M. Bartos. 1994. IFAS extension soil testing laboratory chemical procedure and training manual. Fla Coop. Ext. Serv., IFAS, Univ. Fla, Circ. 812.

Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Circ. 347. California Agricultural Experiment Station, California.

Hochmuth, G.J. 1992. Tips on plant sap testing. Amer. Veg. Grower 40:23-25.

Hochmuth, G.J. and G.A. Clark. 1991. Fertilizer application and management for micro (or drip) irrigated vegetables in Florida. Fla Coop. Ext. Special Series Report SS-VEC-45.

Hochmuth, G.J., D.N. Maynard, and M. Sherman. 1988. Tomato production guide for Florida. Vol. 98C. Fla Coop. Ext. Serv., IFAS, Univ. Fla, Circ. 98C.

Hochmuth, G.J., D.N. Maynard, C.S. Vavrina, and E.A. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Fla Coop. Ext. Special Series Report SS-VEC-42.

Hunt, R. 1978. Plant growth analysis. Edward Arnold, London.

Hunt, R. 1982. Plant growth curves. The functional approach to plant growth analysis. Edward Arnold, London.

Jaworski, C.A. and R.E. Webb. 1966. Yield and growth uniformity of tomato transplants in relation to nutrition levels. Proc. Amer. Soc. Hort. Sci. 79:216-221.

Jaworski, C.A., R.E. Webb, and D.J. Morgan. 1967. Effects of storage and nutrition on tomato transplant quality, survival and fruit yield. Hort. Res. 7:90-96.

Karchi, Z., D.J. Cantliffe, and A. Dagan. 1992. Growth of containerized lettuce transplants supplemented with varying concentrations of nitrogen and phosphorus. Acta Hortic. 319:365-370.

Kemble, J.M., J.M. Davis, R.G. Gardner, and D.C. Sanders. 1994. Root cell volume affects growth of compact-growth-habit tomato transplants. HortScience 29:261-262.

Klassen, P. 1986. Economics dictate using transplants. Amer. Veg. Grower 34:9-14.

Knavel, D.E. 1965. Influence of container, container size, and spacing on growth of transplants and yields in tomato. Proc. Amer. Soc. Hort. Sci. 86:582-586.

Kratky, B.A. and H.Y. Mishima. 1981. Lettuce seedling and yield response to preplant and foliar fertilization during transplant production. J. Amer. Soc. Hort. Sci. 106:3-7.

Krizek, D.T. and D.P. Ormond. 1980. Growth response of 'Grand Rapids' lettuce and 'First Lady' marigold to increased far-red and infrared radiation under controlled environments. J. Amer. Soc. Hort. Sci. 105:936-939.

Leskovar, D.I. and D.J. Cantliffe. 1991. Tomato transplant morphology affected by handling and storage. HortScience 26:1377-1379.

Leskovar, D.I. and D.J. Cantliffe. 1993. Comparison of plant establishment method, transplant, or direct-seeding on growth and yield of bell pepper. J. Amer. Soc. Hort. Sci. 118:17-22.

Leskovar, D.I. and R.R. Heineman. 1994. Greenhouse irrigation systems affect growth of 'TAM-Mild Jalapeno-1' pepper seedlings. HortScience 29:1470-1474.

Leskovar, D.I., D.J. Cantliffe, and P.J. Stoffella. 1991. Growth and yield of tomato plants in response to age of transplants. J. Amer. Soc. Hort. Sci. 116:416-420.

Leskovar, D.I., D.J. Cantliffe, and P.J. Stoffella. 1994. Transplant production systems influence growth and yield of fresh-market tomatoes. J. Amer. Soc. Hort. Sci. 119:662-668.

Liptay, A. and D. Edwards. 1994. Tomato seedling growth in response to variation in root container shape. HortScience. 29:633-635.

Lorenz, O.A. and M.T. Vittum. 1980. Phosphorus nutrition of vegetable crops and sugar beets. The role of phosphorus in agriculture. ASA-CSSA-SSSA, Madison, Wis. p. 737-762 (cited by Widders, 1989).

Masson, J., N. Tremblay, and A. Gosselin. 1991a. Nitrogen fertilization and HPS supplementary lighting influence vegetable transplant production. I. Transplant growth. J. Amer. Soc. Hort. Sci. 116:594-598.

Masson, J., N. Tremblay, and A. Gosselin. 1991b. Effects of nitrogen fertilization and HPS supplementary lighting on vegetable transplant production. II. Yield. J. Amer. Soc. Hort. Sci. 116:599-602.

Maynard, E.T., C.S. Vavrina, and W.D. Scott. 1996. Containerized muskmelon transplants: Cell volume effects on pretransplant development and subsequent yield. HortScience 31:58-61.

Melton, R.R. and R.J. Dufault. 1991. Nitrogen, phosphorus, and potassium fertility regimes affect tomato transplant growth. HortScience 26:141-142.

Neter, J., W. Wasserman, and M.H. Kutner. 1990. Applied linear statistical models: regression, analysis of variance, and experimental designs. 3rd ed. Richard D. Irwin, Inc., Boston.

Nicklow, C.W. and P.A. Minges. 1962. Plant growing factors influencing the field performance of the Fireball tomato variety. Proc. Amer. Soc. Hort. Sci. 81:443-450.

Nicola, S. and D.J. Cantliffe. 1996. Increasing cell size and reducing medium compression enhance lettuce transplant quality and field production. HortScience 31:184-189.

Poniedzialek, M., T. Wojtaszek, E. Kunicki, and R. Suchodolska. 1988. Effect of temperature, supplementary lighting, and pricking-out on the length of the growing period and quality of lettuce transplants for greenhouse production. Bull. Pol. Acad. Sci., Biol. Sci. 36:53-60.

Sadler, R. and D.J. Cantliffe. 1990. Lettuce bolting problems as related to greenhouse grown transplants. Belle Glade EREC Research Report EV-1990-7:55-59.

Soffe, R.W., J.R. Lenton, and G.F.J. Milford. 1977. Effects of photoperiod on some vegetable species. Ann. Appl. Biol. 85:411-415.

Tesi, R. And R. Tallarico. 1984. L'indurimento delle piantine di pomodoro in vivaio e loro resistenza al freddo. Colture Prolette 11:49-54 (cited by Masson et al., 1991a).

Thomas, B.M. 1993. Overview of the Speedling, Inc., transplant industry operation. HortTech. 3:406-408.

Thomas, S.H. 1990. A look at supplementary light fixtures. Greenhouse Manager August:114-115 (cited by Decoteau and Friend, 1991).

Tibbits, T.W., D.C. Morgan, I,J. Warrington. 1983. Growth of lettuce, spinach, mustard, and wheat plants under four combinations of high-pressure sodium, metal halide, and tungsten halogen lamps at equal PPFD. J. Amer. Soc. Hort. Sci. 108:622-630.

Tremblay, N., S. Yelle, and A. Gosselin. 1987. Effects of CO_2 enrichment, nitrogen and phosphorus fertilization on growth and yield of celery transplants. HortScience 22:875-876.

Tremblay, N. and M. Senécal. 1988. Nitrogen and potassium in nutrient solution influence seedling growth of four vegetable species. HortScience 23:1018-1020.

Weston, L.A. 1988. Effect of flat cell size, transplant age, and production site on growth and yield of pepper transplants. HortScience 23:709-711.

Weston, L.A. and B.H. Zandstra. 1986. Effect of root container size and location of production on growth and yield of tomato transplants. J. Amer. Soc. Hort. Sci. 111:498-501.

Weston, L.A. and B.H. Zandstra. 1989. Transplant age and N and P nutrition effects on growth and yield of tomatoes. HortScience 24:88-90.

Widders, I.E. 1989. Pretransplant treatments of N and P influence growth and elemental accumulation in tomato seedlings. J. Amer. Soc. Hort. Sci. 114:416-420.

Wolf, B. 1982. A comprehensive system of leaf analysis and its use for diagnosing crop nutrient status. Comm. Soil Sci. Plant Anal. 13:1035-1059.

Wurr, D.C.E. and J.R. Fellows. 1982. The influence of plant raising conditions on the head weight of crisp lettuce at maturity. J. Agric. Sci., Camb. 99:417-423.

Wurr, D.C.E., J.R. Fellows, and P. Hadley. 1986. The influence of supplementary lighting and mechanically-induced stress during plant raising, on transplant and maturity characteristic of crisp lettuce. J. Hort. Sci. 61:325-330.

BIOGRAPHICAL SKETCH

Puffy Soundy was born on 15 May 1962, in Louis Trichardt, South Africa, to Keystone and Flora Soundy, and is third of five sons. He completed high school in 1979 at Good Hope College, Cape Province, South Africa. He then attended the University of Fort Hare, Alice, South Africa, where he obtained a B.Sc. (Agric.) degree in 1986, majoring in crop science and horticultural science. Through a grant from the Council for Scientific and Industrial Research, Pretoria, South Africa, he pursued an M.Sc. (Agric.) degree at the University of Natal, Pietermaritzburg, South Africa, majoring in horticultural science, which he completed in 1990. Having completed his master's degree, he went back to the University of Fort Hare as a Junior Lecturer in the Department of Agronomy. One year later, he was promoted to Lecturer, a position he held until he got a Fulbright Scholarship to pursue a Ph.D degree at the University of Florida. After completing his degree requirements, he is going back to the University of Fort Hare, where he is currently on study leave. He is presently a member of the

Southern African Society for Horticultural Sciences and the American Society for Horticultural Science.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Daniel J. Cantliffe, Chair
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

George J. Hochmuth, Cochair
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Russell T. Nagata
Associate Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Peter J. Stoffella
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Edward A. Hanlon, Jr.
Professor of Soil and Water Science

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1996

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School